Volume 5, Number 2
ISSN: 0869-5938

March–April 1997

STRATIGRAPHY AND GEOLOGICAL CORRELATION

Official English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

Academician, Russian Academy of Sciences
counsellor of the Presidium of the Russian Academy of Sciences

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК НАУКА/INTERPERIODICA PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief
Boris S. Sokolov
Academician, Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences

Address for correspondence: Staromonetnyi per. 22, Moscow 109180 Russia
Phones: 7-(095) 231-2164; Fax: 7-(095) 233-5590.

Deputy Editor-in-Chief
Mikhail A. Semikhatov
Member of the Russian Academy of Sciences
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Assistant Editor
Aleksei B. Herman
Senior Scientist,
Geological Institute,
Russian Academy of Sciences

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Geological Institute,
Russian Academy of Sciences

Aleksandr S. Alekseev
Professor, Department of Paleontology,
Moscow State University

Mikhail N. Alekseev
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Ivan A. Basov
Dr. Sci. (Geol.-Min.),
Deputy Director, Institute of the Lithosphere,
Russian Academy of Sciences

Michael G. Basset
Professor, National Museum of Wales,
Cardiff, UK

William A. Berggren
Professor, Department of Geology and
Geophysics, Woods Hole Oceanographic
Institute, USA

Elena V. Bibikova
Dr. Sci. (Geol.-Min.), Chief Scientist,
Vernadskii Institute of Geochemistry
and Analytical Chemistry,
Russian Academy of Sciences

Nikita A. Bogdanov
Corresponding Member of the Russian Academy
of Sciences, Director, Institute of the
Lithosphere, Russian Academy of Sciences

Kiyotaka Chinzei
Professor, Institute of Geology,
University of Tokyo, Tokyo, Japan

Nikolai M. Chumakov
Dr. Sci. (Geol.-Min.),
Chief Scientist, Geological Institute,
Russian Academy of Sciences

Yurii B. Gladenkov
Dr. Sci. (Geol.-Min.),
Deputy Director, Geological Institute,
Russian Academy of Sciences

Dmitrii L. Kaljo
Professor, Institute of Geology, Tallinn, Estonia

Victor E. Khain
Member of the Russian Academy of Sciences,
Chief Scientist, Institute of the Lithosphere,
Russian Academy of Sciences

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief, Institute of
Paleontology, Russian Academy of Sciences

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist, Institute of
Paleontology, Russian Academy of Sciences

Jurgen Remane
Professor, Institute de Géologie,
Université de Neuchâtel, Switzerland

Aleksei Yu. Rozanov
Dr. Sci. (Geol.-Min.),
Director, Institute of Paleontology,
Russian Academy of Sciences

Boris A. Sokolov
Dr. Sci. (Geol.-Min.),
Professor, Dean, Faculty of Geology,
Moscow State University

Otto Walliser
Professor,
Göttingen University, Göttingen, Germany

Sun Weigo
Professor, Nanjing Institute of Geology
and Paleontology, Academia Sinica, China

Victor A. Zakharov
Dr. Sci. (Geol.-Min.),
Head of Laboratory, Institute of Geology,
Geophysics, and Mineralogy,
Siberian Branch, Russian Academy
of Sciences, Novosibirsk

Aleksandr I. Zhamoida
Corresponding Member of the Russian Academy
of Sciences, Russian Geological Institute,
St. Petersburg

Staff Editor Tamara V. Trishkina
Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.-Min.)

SCOPE

Stratigraphy and Geological Correlation (Stratigrafiya. Geologicheskaya Korrelyatsiya) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research, and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, Research Alert, SciSearch, *Current Contents* (Physical, Chemical, and Earth Sciences) and *World Translations Index*.

SUBSCRIPTION OFFICE
INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada); FAX: (205) 995-1588

PUBLISHER
MAIK НАУКА/INTERPERIODICA PUBLISHING
PROFSOYUZNAYA UL. 90, MOSCOW, 117864 RUSSIA
PHONE: 7-(095) 336-1600; FAX: 7-(095) 336-0666
E-mail: compmg@maik.rssi.ru

SUBSCRIPTION PRICES (1997, Volume 5, 6 issues)
US $769.00 (North America), $884.00 (other). A 5% discount is given on 2-year orders. Subscriptions may be entered at any time. Orders may be placed at agencies or directly. 5% discount to all subscription agencies. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for (US dollars) $769.00 (North America), outside North America $884.00 per year by MAIK Nauka/Interperiodica Publishing, 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Periodical Postage Paid at Birmingham, Alabama, and additional Mailing Offices. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

Journal founded in 1993.
Original Russian Edition Copyright © 1997 by the Russian Academy of Sciences
and the Division of Geology, Geophysics, Geochemistry, and Mining Sciences.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

Contents

Vol. 5, No. 2, 1997

Simultaneous English language translation of the journal is available from МАИК Наука/Interperiodica Publishing (Russia). *Stratigraphy and Geological Correlation* ISSN 0869-5938.

U–Pb Age of Granitoids in the Junction Zone between the Olekma Granite–Greenstone and Aldan Granulite–Gneiss Terranes
E. B. Sal'nikova, A. B. Kotov, B. V. Belyatskii, S. Z. Yakovleva, I. M. Morozova, N. G. Berezhnaya, and N. Yu. Zagornaya 101

New Data on the Riphean Stratigraphy of Timan
M. E. Raaben and L. I. Oparenkova 110

Fluctuations of Devonian Sea Level in the Moscow Basin
G. D. Rodionova and V. T. Umnova† 118

On the Revised Stratigraphic Scale for the Permian System Adopted at the Second Guadalupian Symposium, Alpine, Texas, USA, April 1996
V. G. Ganelin, A. V. Goman'kov, T. A. Grunt, M. V. Durante, S. S. Lazarev, I. P. Morozova, and A. I. Osipova 126

Correlative Reference Levels of the Permian
G. V. Kotlyar 131

Mid-Cretaceous Phytostratigraphy and Paleobotany of Northern Asia
V. F. Belyi 147

Nannoplankton from Paleogene Deposits in Eastern Kamchatka
E. A. Shcherbinina 156

Brief Communications

Facies Confinement of Paleozoic Acritarchs
N. A. Volkova 167

Devonian Stratigraphy of Mongolian Altai
N. V. Oleneva 171

Radiolarians from Cretaceous Deposits of the Maini–Kakyine Ridge, Koryak Highland
L. G. Bragina and D. I. Vitukhin 176

Biogeochemical Data Used to Identify Synchronous Stratigraphic Levels of the Middle Miocene in Volhynia–Podolia
A. N. Vasil'ev 180

Critics and Discussions

Peculiar Features of Typification in Stratigraphic Classification
S. S. Lazarev 185

Comments to the Article of S.S. Lazarev "Peculiar Features of Typification in Stratigraphic Classification"
A. I. Zhamoida 198

Stratigraphic and Taxonomic Units (Comments to the Paper of S.S. Lazarev "Peculiar Features of Typification in Stratigraphic Classification")
K. V. Simakov 200

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 101–109. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 3–12.
Original Russian Text Copyright © 1997 by Sal'nikova, Kotov, Belyatskii, Yakovleva, Morozova, Berezhnaya, Zagornaya.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

U–Pb Age of Granitoids in the Junction Zone between the Olekma Granite–Greenstone and Aldan Granulite–Gneiss Terranes

E. B. Sal'nikova, A. B. Kotov, B. V. Belyatskii, S. Z. Yakovleva, I. M. Morozova, N. G. Berezhnaya, and N. Yu. Zagornaya

Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, nab. Makarova 2, St. Petersburg, 199034 Russia

Received April 26, 1995

Abstract—U–Pb dating of zircons from the reference granitoid complexes showed that principal thrusts in the northern flank of the junction zone between the Olekma granite–greenstone and Aldan granulite–gneiss terranes of the Aldan Shield were formed 1962 ± 5–2398 ± 4 Ma ago. The oldest structural and metamorphic transformations affected the nonstratified infracrustal complex 3005 ± 4 Ma ago. These data substantiate the reliable correlation of structural units with the geochronological scales previously elaborated for the northern flank and adjacent areas of the Olekma granite–greenstone and Aldan granulite–gneiss terranes.

Key words: *U–Pb method, granitoids, amphibole–biotite tonalite-gneisses, Late Archean, Early Proterozoic, Aldan Shield.*

INTRODUCTION

Basic features of geological structures in the junction zone between the Olekma granite–greenstone (OGGT) and Aldan granulite–gneiss terranes (AGGT) of the Aldan Shield are related in origin to deep-seated "plastic-type" thrusts (*Rannii dokembrii*, 1986; *Dokembriiskaya geologiya*, 1988; Sal'nikova, 1993; *Precambrian Geology*, 1993). Recent geological and geochronological investigations suggest that in the eastern OGGT these thrusts are divisible into three age groups formed in the course of the Late Archean–Early Proterozoic evolution of the Aldan Shield (Sal'nikova, 1993; Sal'nikova *et al.*, 1993; Kotov *et al.*, 1995). Reliable age determinations are available here only for the oldest group of these tectonic elements, whose lower and upper age limits are estimated as 3.0 and 2.6 Ga respectively (Sal'nikova *et al.*, 1993; Kotov *et al.*, 1995). However, in the OGGT–AGGT junction zone and neighboring areas, thrust-type structures have never been studied in their geochronological aspect, and this is a serious problem for any attempt to correlate time scales of successive deformation events elaborated for the OGGT and AGGT (*Rannii dokembrii*, 1986; *Dokembriiskaya geologiya*, 1988; Sal'nikova, 1993; *Precambrian Geology*, 1993). Accordingly, the main purpose of this study was to evaluate the age limits of principal thrusting events in the northern flank of the OGGT–AGGT junction zone by using the U–Pb dating of zircons from the reference granitoid complexes, and to refine the correlation scheme of endogenous processes in this zone and nearby areas of relevant terranes on the basis of new and previously published geochronological data (Kotov *et al.*, 1993, 1995; Sal'nikova *et al.*, 1993).

THE FORMATION SEQUENCE OF GRANITOID COMPLEXES

According to current views (Kitsul and Duk, 1985; *Rannii dokembrii* ..., 1986; *Drevneishie* ..., 1989), the eastern boundary of the OGGT represents a complex system of the Early Archean and Early Proterozoic thrust faults, along which the AGGT rocks overrode the OGGT complexes. These thrusts in the contact OGGT–AGGT zone are responsible for the tectonic juxtaposition of rocks that vary in metamorphic grade from amphibolite to granulite facies and are represented by the nonstratified infracrustal tonalite–trondhjemite gneisses of both terranes, volcano-sedimentary rocks of greenstone belts, and supracrustal sequences of the Aldan megacomplex. The western distribution limit of "tectonic fragments" of granulite-facies metamorphics coincides with the Amga suture zone (Fig. 1), generally considered to be the boundary between the OGGT and AGGT (Neelov, 1968; Neelov and Mil'kevich 1979; *Dokembriiskaya geologiya* ..., 1988; *Precambrian Geology* ..., 1993). The eastern boundary of this junction zone is usually thought to be marked by the disappearance of "tectonic fragments" of the OGGT rocks including the supracrustal formations of greenstone belts (Sal'nikova, 1993).

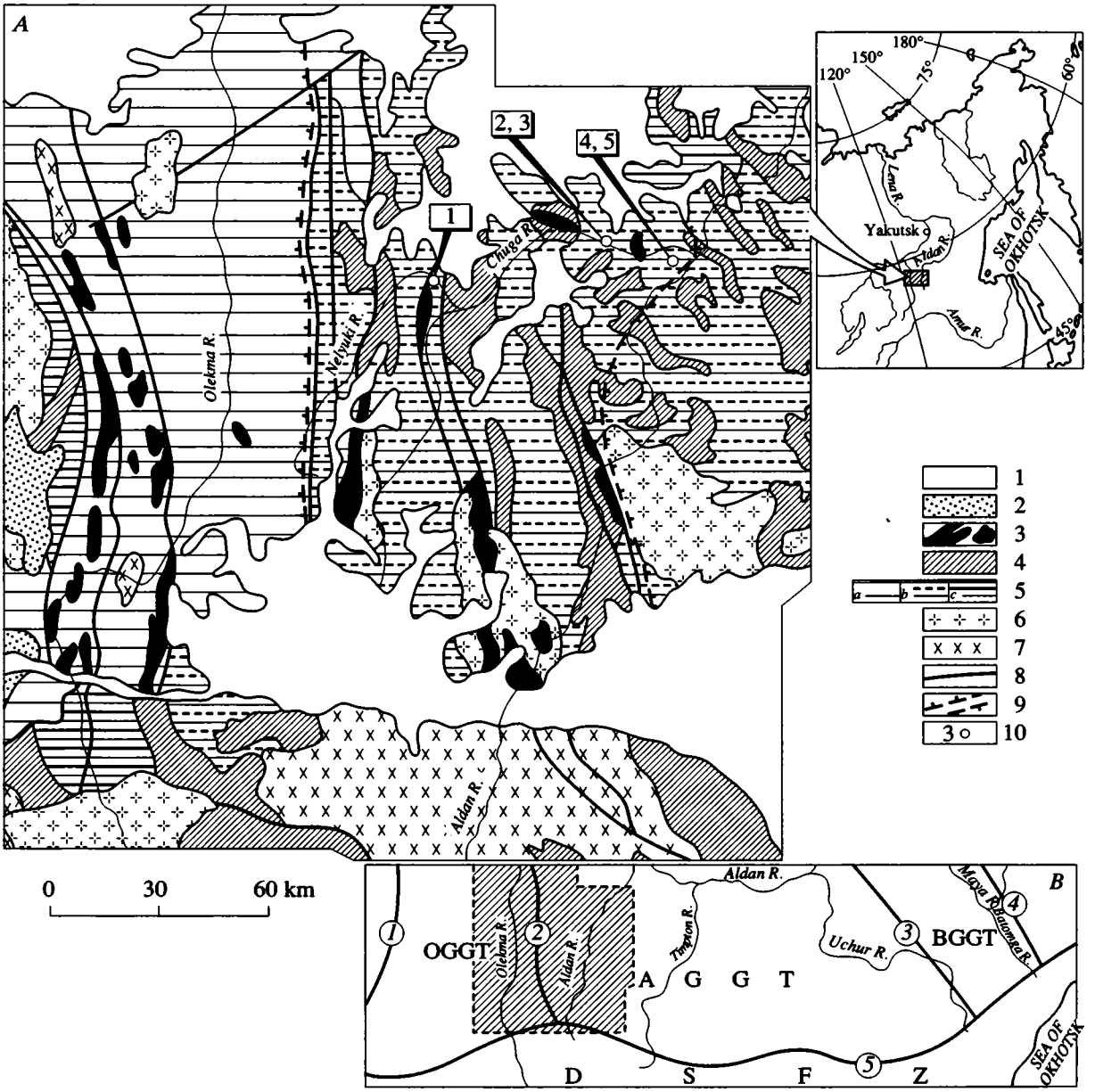


Fig. 1. Schematic geological map of the western Aldan Shield (compiled after data by Duk and his colleagues published in *Rannii dokembrii* ..., 1986; *Dokembriiskaya geologiya* ..., 1988; *Precambrian Geology* ..., 1993).

A: 1, Riphean–Vendian and Paleozoic–Mesozoic deposits; 2, Ugui and Udokan groups (PR_1); 3, Upper Archean greenstone belts; 4, supracrustal formations of the Aldan megacomplex (AR_1); 5, nonstratified infracrustal complex composed of three rock groups, such as (a) biotite and amphibole–biotite gneisses of tonalite–trondhjemite composition, (b) biotite and amphibole–biotite gneisses of tonalite–granite composition with inclusions of hypersthene–biotite gneisses, and (c) hypersthene–biotite gneisses of tonalite–granite composition; 6–7, intrusive magmatic complexes of the Proterozoic (6) and Archean (7); 8, thrust faults; 9, assumed boundaries of the OGGT–AGGT junction zone; 10, sites of geochronological samples C-109 (*1*), H-319-1 (*2*), H-319 (*3*), H-317-4 (*4*), and H-317-1 (*5*).

B: encircled numbers indicate (*1*) Zhuya and Vitim–Nechera faults, (*2*) Amga fault, (*3*) Ulkan fault, (*4*) Nel'kan fault, and (*5*) South-Aldan fault separating the Olekma granite–greenstone (OGGT), Aldan granulite–gneiss (AGGT), Batomga granite–greenstone (BGGT) terranes and Dzhugdzhur–Stanovoi fold zone (DSFZ); the hachured area delineates the map region.

Our reconstruction of the formation sequence of intrusive granitoid complexes in the northern flank of the OGGT–AGGT junction zone is based on the time succession of structural deformations (Table 1). We studied these deformations in outcrops along the banks of the Nelyuki, Chuga, and Aldan rivers beginning from the Kitemelyakh River mouth to the Nelyuki–Chuga confluence point, then downstream from the last point to the junction with the Aldan River, and along the latter near the Malyi Nimnyr River mouth (Fig. 1).

Table 1. Correlation scheme of endogenic processes in the junction zone and nearby areas of the Olekma granite–greenstone and Aldan granulite–gneiss terranes (compiled by Kotov and Sal'nikova)

OGGT, eastern part	OGGT–AGGT junction zone, northern flank	AGGT, northwestern part
S_7—shear zones	S_7—shear zones	S_6—shear zones
γ_4—subalkaline granites	γ_3—subalkaline granites and leucogranites	γ_3—subalkaline granites and leucogranites (1907 ± 15 Ma)
F_{5-6}—sublatitudinal and submeridional open upright folds	F_{5-6}—sublatitudinal and northwestern open upright folds	F_{4-5}—northeastern and submeridional open upright folds
	γ_2—alkaline and subalkaline leucogranites, subalkaline and normal granites	
		γ_2—subalkaline normal and quartz diorites (1962 ± 5 Ma)
F_4, S_4—deep-seated thrust faults	F_4, S_4—deep-seated thrust faults	
γ_3—pegmatites		
F_3—appressed submeridional upright folds	F_3—appressed submeridional upright folds	F_3—appressed northwestern upright folds
F_2, S_2—deep-seated thrust faults	F_2, S_2—deep-seated thrust faults	F_2, S_2—deep-seated thrust faults
	ν_1—dikes of basic rocks	ν_2—dikes of basic rocks
	γ_1—subalkaline granites, subalkaline and normal leucogranites (2398 ± 4, 2423 ± 28, and 2487 ± 5 Ma)	γ_1—subalkaline granites
γ_2—subalkaline granites, granodiorites (2608 ± 18 Ma)		
F_1, S_1—deep-seated faults	F_1, S_1—isoclinal folds, shear zones	F_1, S_1—isoclinal folds, shear zones
ν_1—dikes of basic rocks		ν_1—dikes of basic rocks
γ_1^3—subalkaline granites and granodiorites		
γ_1^2—subalkaline and normal granites, granodiorites		
γ_1^1—multiphase intrusions (3001 ± 3 Ma)		
Formation time of the Tungurcha greenstone belt	Formation time of the Balaganakh and Sogolokh greenstone belts	
S_n—schistosity	S_n—schistosity	S_n—schistosity
	Formation time of the Chuga Group	
		Formation time of the Kurumkan Group
Formation time of the nonstratified infracrustal complex (3016 ± 8–3212 ± 8 Ma)	Formation time of the nonstratified infracrustal complex (3184 ± 85 Ma)	Formation time of the nonstratified infracrustal complex (3335 ± 3 Ma)

In the studied part of the OGGT–AGGT junction zone, the geological structure is composed of alternating tectonic slices of variable thickness. Rocks in these slices are usually represented either by amphibolite-facies metamorphics (amphibole–biotite and biotite tonalite-gneisses and granite-gneisses of the infracrustal complex, and rocks of the Chuga Formation, such as garnet–biotite and amphibole plagiogneisses, high-Al gneisses, garnet amphibolites, carbonate–silicate rocks, calciphyres, and quartzites), or by volcanosedimentary deposits of the Balaganakh and Sogolokh greenstone belts. Less abundant rocks of granulite facies, such as hypersthene–biotite tonalite-gneisses and two-pyroxene schists, were recognized only in the mouth areas of the Nelyuki and Chuga rivers (Fig. 1).

As already noted, thrust faults in the eastern OGGT can be attributed to three age groups (Kotov *et al.*, 1993, 1995; Sal'nikova, 1993; Sal'nikova *et al.*, 1993). However in the northern flank of the OGGT–AGGT junction zone, the most significant structural and metamorphic transformations were related in origin to the formation of second and third groups of thrust faults (Table 1). The second group includes such structural elements as subhorizontal shear zones S_2 and isoclinal recumbent folds F_2 with sublatitudinal hinges. They were generated after the formation of shear zones S_1

and isoclinal recumbent folds F_1, which bend the migmatite banding and crystallization schistosity S_n in the infracrustal amphibole–biotite and biotite tonalite-gneisses. It is possible that the appearance of structural elements F_1 and S_1 reflects one more stage of deep crustal displacements in the eastern OGGT, which can be attributed to thrusts of the first age group. At present, however, it is impossible to infer the character of tectonic movements responsible for the origin of structural elements S_1. The shear zones S_2 and axial surfaces of the F_2 folds are deformed into submeridional upright folds F_3, which are appressed and have low-angle hinges.

The structural paragenesis of thrusts attributed to the third age group includes such elements as subhorizontal shear zones S_4 and recumbent folds with submeridional hinges F_4. The latest structural elements are represented by open upright folds F_{5-6} and subvertical shear zones S_7.

Taking into account geological relations between time-differentiated structural elements, we distinguished the following groups of intrusive granitoid complexes occurring in the northern flank of the OGGT–AGGT junction zone (Table 1):

(1) Porphyroid amphibole–biotite granites,[1] fine- to medium-grained biotite leucogranites, and subalkaline granites or leucogranites γ_1, which compose plate-like bodies (up to 500 m in apparent thickness) intercalated with rocks of the infracrustal complex and Chuga Formation. In the course of structural and metamorphic transformations induced by the second thrusting stage, the contact planes of γ_1 granitoid bodies were oriented parallel to planar structural elements of enclosing rocks. As a result, we may evaluate the lower age limit for the emplacement period of γ_1 granitoids by using only indirect arguments, for instance, the absence of structural and metamorphic features in these rocks that predate structural elements S_2 and F_2. In the regional geochronological scale (*Rannii dokembrii* ..., 1986), this group of granitoids is referred to the Early Archean intrusive complexes.

(2) Pegmatoid and subalkaline granites γ_2 associated with subalkaline to alkaline leucogranites and occurring as dikes or vein bodies whose thickness is from 0.3 to 3 m. Contact planes of γ_2 granitoids, which are deformed into open folds F_{5-6}, crosscut structural elements S_4 and F_4 related to the second age group of thrusts.

(3) Biotite–amphibole granites and subalkaline aplitic or leucocratic granites occurring as minor massifs and thin dikes, which crosscut limbs and axial surfaces of the F_{5-6} folds. The rocks were highly foliated at the formation time of shear zones S_7.

[1] Rock names in this work are given according to recommendations published in *Magmaticheskie gornye porody* ... (1985).

ANALYTICAL TECHNIQUE

Zircon grains were extracted by the standard heavy-liquid method of mineral separation. Chemical decomposition of zircons and concentration of U and Pb for isotopic measurements were performed following the modified Krogh's method (Krogh, 1973). Crushed zircons were divided into density fractions by centrifuging in the heated Clerici solution with specific weight of 4.2–4.5 g/cm^3. We used a static working regime of the multicollector mass spectrometer Finnigan MAT-261 for the isotopic measurements. The accuracy of the determinations was 1% for U and Pb concentrations, and 0.5% for U/Pb ratios. The total blank was less than 0.2 ng for Pb, and 0.01 ng for U. Experimental data were processed by using computer programs PbDAT and ISOPLOT (Ludwig, 1991a, 1991b). The error level is equal to 2σ. Age values are calculated by applying generally accepted decay constants of uranium (Steiger and Jager, 1976). Corrections for common lead are based on the model parameters (Stacey and Kramers, 1975).

RESULTS AND DISCUSSION OF U–Pb GEOCHRONOLOGICAL DATA

Amphibole–biotite tonalite-gneisses of the infracrustal complex, which experienced structural and metamorphic transformations beginning from the formation time of S_n foliation, and granitoids γ_1, whose emplacement preceded the formation stage of thrusts of the second group, were the main objects of our geochronological investigations. Sampling sites are shown in Fig. 1, and investigation results are presented in Tables 2–5 and Figs. 2–5.

Amphibole–biotite tonalite-gneisses of the infracrustal complex. Sample H-317-4 of amphibole–biotite tonalite-gneiss is from an exposure at the right bank of the Aldan River near the mouth of the Malyi Nimnyr River (Fig. 1). This locality displays alternating tectonic sheets (S_2), which are composed of migmatized tonalite- and granite-gneisses of infracrustal complex and high-Al gneisses of the Chuga Formation associated with granitoids γ_1. Near the sampling location, the most intense structural and metamorphic transformations are related in time to the formation stage of schistosity S_2. In addition, the rocks demonstrate another foliation system (S_1 and/or S_n) and migmatite banding, both deformed by recumbent folds F_2.

Zircons from Sample H-317-4 are represented by crystals of two morphologic types. Light-yellow to light-brown subidiomorphic prismatic crystals of the first type have a zircon habit and heterogeneous inner structure. These crystals usually consist of a prismatic core with fine zoning, which is surrounded by an envelope with intermittent zoning, and then by a thin highly birefringent rim. We should note that cores in these zircons show variable birefringence. Their sizes vary from 50 to 325 μm, elongation coefficient K_{el} = 1.6–3.3. Zircons of the second type are represented by fine

(40–100 μm) colorless transparent crystals without cores, which are of a rounded polyface habit and show relic zoning (K_{el} = 1.0–1.6).

For the initial U–Pb isotope measurements, we used three size fractions of zircon crystals: one of them (–60 μm) mostly consisted of crystals of the second type, and two others (+60–70 and +70–100 μm) included both zircon types (runs 1–3 in Table 2 and respective points in Fig. 2). As shown in Fig. 2, data points corresponding to the isotopic composition of these fractions plot apart from concordia. To diminish the discordance, we treated zircons of the first type (fraction of +70–100 μm) by using the air abrasion technique (Krogh, 1982) and divided another fraction of –60 μm (crystals of the second type) by density. Data points for the initial zircon fractions (points 1–3 in Fig. 2), residue after abrasion (the first type zircons from the fraction of +70–100 μm, point 4 in Fig. 2), and light zircons of the second type (point 5 in Fig. 2) plot on discordia, whose upper and lower intersects with concordia correspond to the age values of 3184 ± 85 and 742 ± 209 Ma respectively; MSWD = 2.6 (Fig. 2). The data point for the heavy fraction of the second type zircons (point 6 in Fig. 2) well fits to concordia. The estimated $^{207}Pb/^{206}Pb$ age of this fraction is 3005 ± 4 Ma (Table 2).

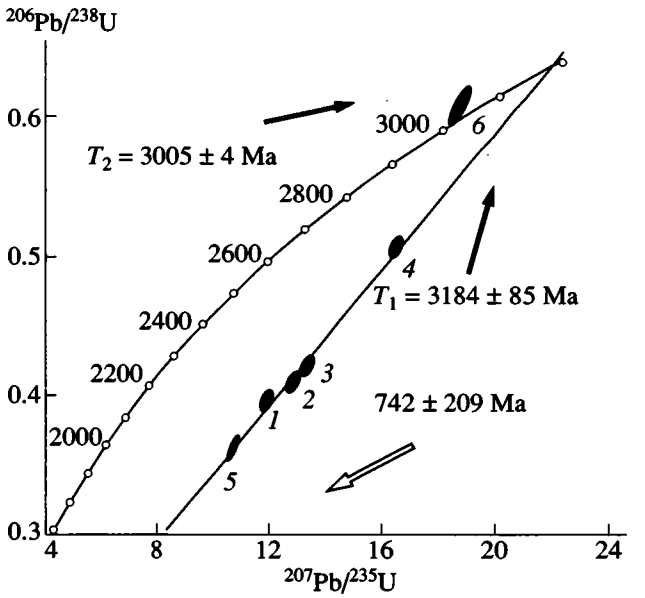


Fig. 2. Concordia diagram for zircons from amphibole–biotite tonalite gneiss of infracrustal complex (Sample H-317-4) with data points numbered as experimental runs in Table 2 (here and in subsequent diagrams, black ovals delineating error ranges of calculated U/Pb ratios are twofold enlarged).

These results of U–Pb isotope studies suggest that infracrustal amphibole–biotite tonalite-gneisses bear zircons of two morphologic types different in age. To a first approximation, the upper intersect age of 3184 ± 85 Ma may indicate the formation stage of a magmatic protolith for the studied tonalite-gneisses, because the discordia is defined chiefly by the core-bearing zircons of the first type. The outer zones of these crystals and the second type zircons were probably formed during the metamorphism of the high-T amphibolite facies, i.e., concurrently with the formation of migmatite banding and schistosity S_1 and/or S_n. These elements of rock fabrics are younger than schistosity S_2, whose age, as we will see below, is not older than 2.4 Ma. Apparently, we have sufficient grounds to believe that concordant age of 3005 ±4 Ma for the heavy fraction of the second type zircon corresponds to the time of the oldest structural and metamorphic transformations of infracrustal rocks in the northern flank of the OGGT–AGGT junction zone.

Porphyroid amphibole–biotite granites γ_1. Sample H-319-1 that we used for U–Pb isotopic dating is from

Table 2. U–Pb isotopic data for zircons from amphibole–biotite tonalite-gneisses of the nonstratified infracrustal complex

Ordinal number of experimental runs	Sample number, fraction size (μm) and its characteristics	Sample weight, mg	Concentration, ppb		Measured isotopic ratios			Recalculated isotopic ratios		$^{207}Pb/^{206}Pb$ age, Ma
			Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	
1	H-317-4, –60	3.12	391	640	11784	0.2207	0.5735	0.3951	11.992	2990 ± 6
2	H-317-4, +60–70	2.19	338	613	11095	0.2287	0.3250	0.4109	12.914	3040 ± 10
3	H-317-4, +70–100	2.07	375	628	14253	0.2296	0.4283	0.4183	13.231	3048 ± 6
4	H-317-4, +70–100 AA 64.5%	2.88	375	620	736	0.2512	0.1170	0.5051	16.476	3100 ± 5
5	H-317-4, –60, LF	18.1	286	574	2105	0.2212	0.3759	0.3599	10.709	2955 ± 2
6	H-317-4, –60, HF	12.8	364	344	5714	0.2253	0.7778	0.6097	18.812	3005 ± 4

Note: AA, percentage of fraction removed by air abrasion; LF, light zircon fraction; HF, heavy zircon fraction.

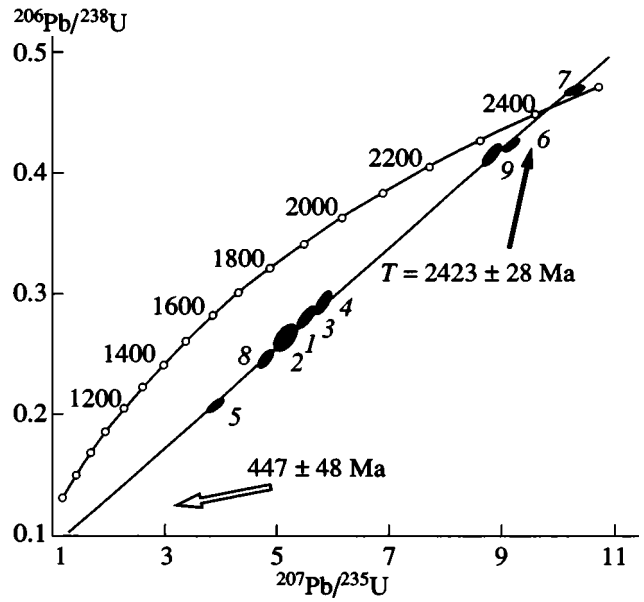


Fig. 3. Concordia diagram for zircons from porphyroid amphibole–biotite granites γ_1 (Sample H-319-1) with data points numbered as experimental runs in Table 3.

the bank exposure of highly foliated (S_2) porphyroid amphibole–biotite gneisses located in the middle course of the Chuga River (Fig. 1). The accessory zircons of the sample occur as subidiomorphic transparent or translucent crystals of the long-prismatic zircon habit. They are pale-pink, usually fractured, and show high birefringence. Few crystals enclose rounded cores and display magmatic zoning. Sometimes, the crystal faces demonstrate growth and dissolution marks. The size range of crystals is 40–250 μm, $K_{el} = 3.0–4.0$.

At first, we analyzed two zircon fractions of –100 and +100–125 μm, and also a sample of twenty of the best preserved zircon grains; however, all isotopic compositions in these runs turned out to be entirely discordant (runs 1–3 and 8 in Table 3, and the respective points in Fig. 3). Afterward, we divided the zircons by density and subjected them to the preliminary acid treatment (Makeev, 1981) in order to lower the discordance degree. In the last case, powdered zircon samples were treated in a mixture of 35% HF and 9% HNO_3 for two hours under a temperature of 220°C. To remove the dissolved part of the sample, we repeatedly leached it in the concentrated HCl, and the residue (insoluble phase) was analyzed by the standard method.

Data for zircon fractions of –50 μm different in density did not decrease the discordance (points 4 and 5 in Fig. 3). Much more concordant are heavy zircons separated from the fraction of +100 μm (point 9 in Fig. 3), and a further decrease in discordance was obtained after the acid treatment of the samples. Data points corresponding to the isotopic compositions of two residual zircon fractions of +100–150 μm (points 6 and 7 in Fig. 3) plot very close to concordia, and their $^{207}Pb/^{206}Pb$ age is estimated as equal to 2419 ± 3 and 2439 ± 17 Ma respectively (Table 3). The resulting discordia for zircons, which have been extracted from Sample H-319-1, is based on nine points (Fig. 3). Its upper and lower intercepts with concordia yield age values of 2423 ± 28 and 447 ± 48 Ma, MSWD = 48.

Biotite leucogranites γ_1. We also extracted zircons for U–Pb isotope study from two samples of foliated (S_2) medium-grained biotite leucogranites. One (H-319)

Table 3. U–Pb isotopic data for zircons from porphyroid amphibole–biotite granites γ_1

Ordinal number of experimental runs	Sample number, fraction size (μm) and its characteristics	Sample weight, mg	Concentration, ppb		Measured isotopic ratios			Recalculated isotopic ratios		$^{207}Pb/^{206}Pb$ age, Ma
			Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	
1	H-319-1, –100	0.77	84.7	269	1145	0.1541	0.2254	0.2619	5.1654	2264 ± 5
2	H-319-1, –100	5.27	118	376	1815	0.1497	0.2116	0.2662	5.2438	2265 ± 4
3	H-319-1, $2O_3$	–	0.01*	0.03*	681	0.1638	0.2440	0.2886	5.7758	2289 ± 6
4	H-319-1, –50, HF	0.49	68.3	205	1604	0.1510	0.2262	0.2798	5.5208	2265 ± 3
5	H-319-1, –50, LF	0.65	85.1	350	1063	0.1482	0.2027	0.2068	3.8827	2179 ± 5
6	H-319-1, +100–150, UF	3.29	30.1	57.8	1670	0.1640	0.2498	0.4241	9.1590	2419 ± 3
7	H-319-1, +100–150, UF	6.80	37.0	64.0	2175	0.1641	0.2544	0.4703	10.276	2439 ± 17
8	H-319-1, +100–125	3.95	124	421	1338	0.1521	0.2290	0.2450	4.8246	2265 ± 2
9	H-319-1, +100, HF	5.03	73.4	113	165.4	0.2280	0.4363	0.4153	8.8177	2462 ± 5

Note: LF, light zircon fraction; HF, heavy zircon fraction; UF, unsolved fraction after acid treatment; $2O_3$, number of individual zircon grains in the sample; * by calculations, initial sample weight is conventionally accepted as equal to 1 g.

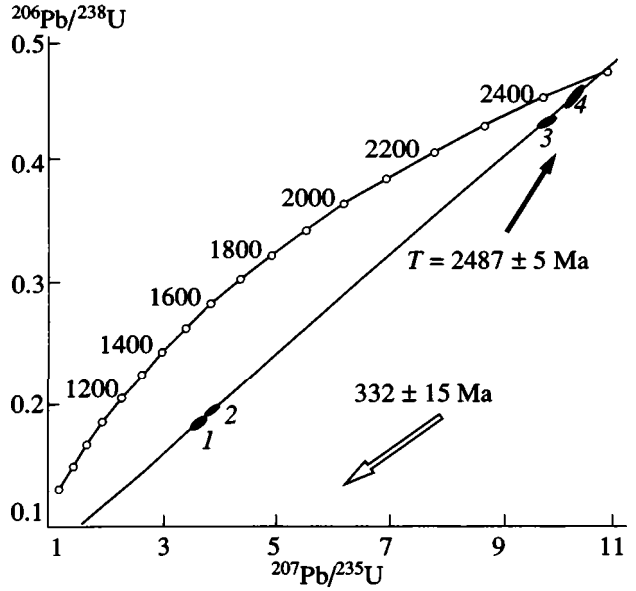


Fig. 4. Concordia diagram for zircons from biotite leucogranites γ_1 (samples H-319 and C-109) with data points numbered as experimental runs in Table 4.

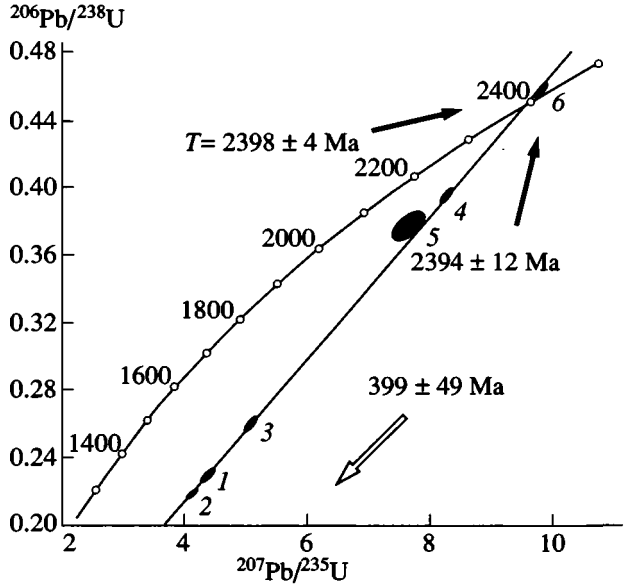


Fig. 5. Concordia diagram for zircons from subalkaline biotite leucogranites γ_1 (Sample H-317-1) with data points numbered as experimental runs in Table 5.

was sampled in the previous locality near to the porphyroid amphibole–biotite granite H-319-1, and another (C-109) is from a bank exposure located near the mouth of the Nelyuki River (Fig. 1).

Both samples yielded zircons identical in morphology and inner structure; their light-pink crystals are of a long-prismatic habit, lack cores, and display magmatic zoning. The crystal size varies from 40 to 200 μm, K_{el} = 3.0–3.5. Rare, highly birefringent crystals of the flattened or short-prismatic habit occur only in the fraction of –50 μm. We should also add that zircons from Sample H-319 are ferruginate, hazy, and highly fractured.

The preliminary U–Pb study of two zircon fractions (+50–100 and +150 μm) from Sample H-319 revealed significantly discordant U/Pb ratios (runs 1 and 2 in Table 4, and the respective points in Fig. 4). Accordingly, the zircon fraction of –135 μm from Sample C-109 was subjected to preliminary acid treatment, first for two and then for three hours (points 3 and 4 in Fig. 4), using the procedure described above. Data points for respective residual fractions as well as for studied zircons from Sample H-319 plot on a single discordia, whose upper and lower intersections with concordia correspond to age values of 2487 ± 5 and 332 ± 15 Ma, respectively; MSWD = 4 (Fig. 4). We should also note that the insoluble phase obtained after 3-hour acid treatment of zircons from Sample C-109 is almost concordant. The estimated $^{207}Pb/^{206}Pb$ age for this residue is 2482 ± 1 Ma (Table 4), and coincides with the upper

Table 4. U–Pb isotopic data for zircons from biotite leucogranites γ_1

Ordinal number of experimental runs	Sample number, fraction size (μm) and its characteristics	Sample weight, mg	Concentration, ppb		Measured isotopic ratios			Recalculated isotopic ratios		$^{207}Pb/^{206}Pb$ age, Ma
			Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	
1	H-319, +50–100	0.79	135	627	1184	0.1527	0.1871	0.1853	3.6265	2251 ± 4
2	H-319, +150	1.32	127	567	1698	0.1507	0.1693	0.1957	3.8660	2267 ± 3
3	C-109, –135, UF	–	0.03*	0.05*	710	0.1799	0.1904	0.4319	9.6698	2480 ± 11
4	C-109, –135, UF	–	0.03*	0.05*	3763	0.1656	0.1494	0.4544	10.180	2482 ± 1

Note: UF, unsolved fraction after acid treatment; * by calculations, initial sample weight is conventionally accepted as equal to 1 g.

Table 5. U–Pb isotopic data for zircons from subalkaline biotite leucogranites γ_1

Ordinal number of experimental runs	Sample number, fraction size (μm) and its characteristics	Sample weight, mg	Concentration, ppb		Measured isotopic ratios			Recalculated isotopic ratios		$^{207}Pb/^{206}Pb$ age, Ma
			Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	
1	H-317-1, –70	9.70	226	746	2099	0.1447	0.3890	0.2276	4.3518	2211 ± 3
2	H-317-1, +125	5.15	181	739	2340	0.1431	0.1515	0.2188	4.1543	2198 ± 2
3	H-317-1, +125, AA 34%	2.77	170	597	3774	0.1445	0.1335	0.2606	5.0739	2242 ± 2
4	H-317-1, +125, AA 78%	2.08	432	930	1792	0.1583	0.2016	0.3951	8.2466	2362 ± 3
5	H-317-1, +100–125, HF	14.2	71.5	122	184.3	0.2166	0.4560	0.3760	7.6299	2313 ± 29
6	H-317-1, +125, UF	0.88	124	211	1279	0.1645	0.3255	0.4549	9.7030	2398 ± 4

Note: AA, percentage of fraction removed by air abrasion; HF, heavy zircon fraction; UF, unsolved fraction after acid treatment.

intersect age, which approximates data points for all the zircon fractions studied.

Subalkaline biotite leucogranites γ_1. Sample H-317-1 is from a bank exposure of subalkaline biotite granites located near the confluence of the Malyi Nimnyr and Aldan rivers (Fig. 1). Accessory zircons from this sample are represented by subidiomorphic pink-yellow hazy crystals, which display magmatic zoning. The size range of crystals is 50–450 μm, K_{el} = 2.0–3.0.

We initially investigated two zircon fractions of –70 and +125 μm (runs 1 and 2 in Table 5, and respective points in Fig. 5), which turned out to be highly discordant. At the next stage, we used air abrasion, density separation, and acid treatment of zircons. After the first run of air abrasion (34%) applied to the zircon fraction of +125 μm, the change in isotopic composition was insignificant (point 3 in Fig. 5). The deep abrasion (78%) made this fraction more concordant (point 4 in Fig. 5), and the data points of heavy zircons from the fraction of +100–125 μm also approach concordia (point 5 in Fig. 5). The isotopic composition of insoluble residue after the acid treatment during one hour (point 6 in Fig. 5) plots exactly on the concordia and corresponds to the $^{207}Pb/^{206}Pb$ age of 2398 ± 4 Ma (Table 5). In total, the regression line approximating all data points for Sample H-317-1 intersects the concordia at the points corresponding to the ages of 2394 ± 12 and 399 ± 49 Ma (Fig. 5). Taking into account that the last zircon fraction is also located at the discordia line, we may consider its concordant age of 2398 ± 4 Ma as corresponding to the crystallization time of zircons extracted from Sample H-317-1 of subalkaline biotite leucogranite γ_1.

According to the morphology and inner structure described above, zircons from all granitoids γ_1 are minerals of magmatic origin. This suggests that zircon ages of 2487 ± 5, 2423 ± 28, and 2398 ± 4 Ma define the crystallization time of melts that were parental for these granitoids.

CONCLUSION

Geochronological data presented here show that protolith of the amphibole–biotite tonalite-gneiss from the nonstratified infracrustal complex of the northern flank of the OGGT–AGGT junction zone was about 3184 ± 85 Ma in age. This affords an opportunity to correlate this rock with amphibole–biotite and biotite gneisses of tonalite–trondhjemite composition from the nonstratified infracrustal complex of OGGT. This complex is subdivided into age groups of 3016 ± 8 and 3212 ± 8 Ma (Nutman *et al.*, 1992), whereas infracrustal hypersthene–biotite tonalite-gneisses from the northwestern AGGT are 3335 ± 3 Ma old (Nutman *et al.*, 1992).

The earliest structural and metamorphic transformations affected the infracrustal complex in the northern flank of the OGGT–AGGT junction zone about 3005 ± 5 Ma ago. The gabbro–diorite–tonalite–trondhjemite Tungurchakan massif is of a similar age (γ_1^1 in Table 1; U–Pb zircon age of 3001 ± 3 Ma according to Sal'nikova *et al.*, 1993) and was formed before the deep-seated thrusts of the first age group distinguished in the eastern OGGT. Taking these data into account, we may consider the earliest structural elements (S_n) of the infracrustal complex of the junction zone and OGGT proper as compatible in age. In its turn, it suggests a correlation of recumbent folds F_1 and crystallization schistosity S_1 occuring in the OGGT–AGGT junction zone with structural elements of the deep-seated thrusts of the second age group within the eastern OGGT. In the northwestern AGGT, possible analogues of these elements are represented by recumbent folds F_1 and crystallization schistosity S_1.

The emplacement of K-series granitoids γ_1, which are widespread in the northern flank of the OGGT–AGGT junction zone, occurred 2398 ± 4–2485 ± 5 Ma ago; i.e., it was related to the Early Proterozoic, but not to the Archean evolution (*Rannii dokembrii* ..., 1986) of

the Aldan Shield. Granitoids γ_1 experienced structural and metamorphic transformations only since the formation time of deep-seated thrusts of the second age group. Accordingly, the maximum age limit of this group is not older than 2.4 Ga. It should be stressed that structural elements of the second group are definitely detectable not only in the eastern OGGT and the junction zone, but also in the northwestern AGGT (Sal'nikova, 1993). Therefore, they can be used as general reference points in the correlation of sequential deformations identified in both terranes. The minimum age limit for the formation time of deep-seated thrusts in the OGGT–AGGT junction zone can be deduced only from geochronological data obtained for subalkaline and quartz diorites of the northwestern AGGT (γ_2, Table 1), whose emplacement was likely after the formation of deep-seated thrusts of the third age group. The U–Pb zircon age for these granitoid intrusions is 1962 ± 5 Ma (Kotov *et al.*, 1993).

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project no. 94-05-17043) and the International Science Foundation (grant no. R1A000).

Reviewer E.V. Bibikova

REFERENCES

Dokembriiskaya geologiya SSSR (Precambrian Geology of the USSR), Rundqvist, D.V. and Mitrofanov, F.P., Eds., Leningrad: Nauka, 1988.

Drevneishie porody Aldano-Stanovogo shchita: Putevoditel' Mezhdunarodnoi geologicheskoi ekskursii Proekta MPGK N. 280 "Drevneishie porody Zemli" (The Most Ancient Rocks of the Aldan–Stanovoi Shield: A Guide Book for the International Geological Excursion of the IPGC Project no. 280 "The Most Ancient Rocks of the Earth"), Leningrad, 1989.

Kitsul, V.I. and Duk, V.L., Endogenic Conditions of Formation and Evolutionary Stages of the Early Precambrian Lithosphere in the Vitim–Aldan Shield, in *Endogennye rezhimy formirovaniya zemnoi kory i rudoobrazovaniya v rannem dokembrii* (Endogenic Regimes of Earth Crust Formation and Ore Genesis in the Early Precambrian), Leningrad: Nauka, 1985, pp. 217–235.

Kotov, A.B., Sal'nikova, E.B., Morozova, I.M., *et al.*, Early Proterozoic Granitoids in the Northwestern Part of the Aldan Granulite–Gneiss Terrane (Aldan Shield): U–Pb and Sm–Nd Data, *Geol. Geofiz.*, 1993, no. 2, pp. 15–21.

Krogh, T.E., A Low-Contamination Method for Hydrothermal Decomposition of Zircon and Extraction of U and Pb for Isotopic Age Determination, *Geochim. Cosmochim. Acta*, 1973, vol. 37, pp. 485–494.

Krogh, T.E., Improved Accuracy of U–Pb Zircon Dating by the Creation of More Concordant System Using an Air Abrasion Technique, *Geochim. Cosmochim. Acta*, 1982, vol. 46, pp. 637–649.

Ludwig, K.R., PbDat for MS-DOS, Version 1.21, *U.S. Geol. Survey Open-File Rept.*, 1991a, no. 88-542, pp. 1–35.

Ludwig, K.R., ISOPLOT for MS-DOS, Version 2.50, *U.S. Geol. Survey Open-File Rept.*, 1991b, no. 88-557, pp. 1–64.

Magmaticheskie gornye porody: Klassifikatsiya, nomenklatura, petrografiya (Magmatic Rocks: Classification, Nomenclature, Petrography), Bogatikov, O.A., Ed., Moscow: Nauka, 1985.

Makeev, A.F., *Radiatsionno-khimichskie prevrashcheniya tsirkonov i ikh primenenie v geokhronologii* (Radio-Chemical Transformations in Zircons as Applied to Geochronology), Leningrad: Nauka, 1981.

Neelov, A.N., Precambrian Tectonics of the Siberian Platform and Some Regularities in the Evolution of Precambrian Mobil Zones, in *Geologiya dokembriya: 23 sessiya MGK* (Geology of the Precambrian: 23rd Int. Geol. Congr.), Leningrad: Nauka, 1968, pp. 41–51.

Neelov, A.N. and Mil'kevich, R.I., *Petrokhimiya metamorficheskikh kompleksov Yugo-Vostochnoi Sibiri* (Petrochemisry of Metamorphic Complexes in Southeastern Siberia), Leningrad: Nauka, 1979.

Nutman, A.P., Chernyshev, I.V., Baadsgaard, H., and Smelov, A.P., The Aldan Shield of Siberia, USSR: The Age of Its Archean Components and Evidence for Widespread Reworking in the Mid-Proterozoic, *Precambrian Res.*, 1992, vol. 54, pp. 195–210.

Precambrian Geology of the USSR, Rundqvist, D.V. and Mitrofanov, F.P., Eds., Amsterdam: Elsevier, 1993.

Rannii dokembrii Yuzhnoi Yakutii (Early Precambrian in the Southern Yakutia), Dobretsov, N.L., Ed., Moscow: Nauka, 1986.

Sal'nikova, E.B., Tectono-Magmatic Evolution in the Northern Flank of Junction between the Olekma Granite–Greenstone and Aldan Granulite–Gneiss Terranes of the Aldan Shield, *Cand. Sci. (Geol.–Mineral.) Dissertation*, St. Petersburg: Inst. Precambrian Geol. Geochronol., Russ. Acad. Sci., 1993.

Sal'nikova, E.B., Kotov, A.B., Nemchin, A.A., *et al.*, Age of the Tungurchakan Massif (Olekma Granite–Greenstone Terrane, the Aldan Shield), *Dokl. Ross. Akad. Nauk*, 1993, vol. 331, no. 3, pp. 356–358.

Stacey, J.S. and Kramers, I.D., Approximation of Terrestrial Lead Isotope Evolution by a Two-Stage Model, *Earth Planet. Sci. Lett.*, 1975, vol. 26, pp. 207–221.

Steiger, R.H. and Jager, E., Subcommission on Geochronology: Conversion of the Use of Decay Constants in Geo- and Cosmochronology, *Earth Planet. Sci. Lett.*, 1976, vol. 36, pp. 359–362.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 110–117. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 13–20.
Original Russian Text Copyright © 1997 by Raaben, Oparenkova.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

New Data on the Riphean Stratigraphy of Timan

M. E. Raaben* and L. I. Oparenkova**

** Geological Institute (GIN), Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*
*** Ukhta Expedition of Geological Exploration, Portovaya ul. 9, Ukhta, 169400 Russia*

Received December 29, 1994; in final form, December 6, 1995

Abstract—The Upper Riphean biostratigraphic characteristic of the Timan was supplemented with the new data provided by the drilling of a number of wells in the Tsil'menskii Kamen' region. Its western sections include abundant stromatolite beds extending up to the south of northern Timan and displaying the complete succession of horizons, from the Yurezan' to Suleimanovo one, distinguished in the southern Ural stratotype of the Karatavian. The Sim Horizon with characteristic stromatolite beds yielding *Conophyton garganicus* var. *ikeni* Raab. et Komar and *Baicalia* ex gr. *prima* Semikh., was recorded for the first time outside the southern Urals. In the local stratigraphic scheme it corresponds to most of the lower part of the Pav"yug Formation. The upper part of this formation is characterized by the rich stromatolite assemblage of the Suleimanovo Horizon and boundary sediments of the Minka Horizon. Stromatolite-bearing carbonate sequences are partly substituted by shaly sediments in southeastern sections of the Tsil'menskii Kamen' region.

Key words: *Riphean, stromatolites, horizon, Karatavian, stratigraphy, correlation.*

The Upper Precambrian stratigraphy of the Timan Ridge, essential for the comprehension of the structure and formation of the basement of the East European craton, faced some problems from the outset and still runs into obstacles. Their solution is complicated, on the one hand, by peculiarities of the section itself, which includes abundant monotonous shaly sequences disturbed by rather intense fault tectonics, and on the other hand, by the discreteness of Precambrian outcrop areas in uplifts, which are poorly exposed. At the early stage of investigation this resulted in the development of various contradictory stratigraphic schemes (Zhuravlev *et al.*, 1966). The lack of factual evidence remains until today. Along with the deficit of isotopic geochronologic data, it prevents the refinement of the Riphean stratigraphic scale of the Timan and of the Upper Precambrian correlation scheme for the north of European Russia, both adopted by ISC in 1985 as working schemes (*Rifei* ..., 1987).

New supplementary data were obtained recently by drilling and field investigations in the Tsil'ma uplift located in the upper reaches of the Tsil'ma and Rochuga rivers near the southern end of the northern Timan (Fig. 1). This area is adjacent to the central Timan uplifts, whose sections provided the basis for the general Upper Precambrian stratigraphy of the region. Our paper deals mainly with biostratigraphic characteristics of carbonate stromatolite sequences, which are major markers for the correlation of Precambrian deposits in Timan. The investigation of many samples from wells and outcrops (more than 80 samples collected by L.I. Oparenkova, V.M. Pachukovskii, and V.N. Oparenkov) considerably supplemented the available data on the Riphean stromatolites from Timan. As will be discussed later, the new data raise the question of applying some corrections to the stratigraphic concept now accepted.

The recent Upper Riphean stratigraphic scheme of the Timan includes two carbonate formations, the Pav"yug and Vorykva ones. The former is correlated with the Min'yar Formation and the latter with the whole underlying post-Zil'merdak interval of the Karatau Group of the stratotype (Table 1). Except for a few areas, only the younger Pav"yug Formation is exposed to the daylight. Its outcrops are known in main Timan uplifts, namely, in the Dzhezhim-Parma and Och-Parma (southern Timan), and also in the Chetlass and Tsil'menskii Kamen' (middle and northern Timan). The formation is usually considered as the most reliable marker among sedimentary-metamorphic units of the region (Ivensen, 1964; Getsen, 1975; and others). This carbonate stromatolite-bearing unit was first distinguished at the Dzhezhim-Parma locality as presumably Devonian "shaly dolomite formation" (Miloradovich, 1938). In the 1940s it was distinguished under different names in the Och-Parma and Chetlasskii Kamen' localities (the review of Zhuravlev *et al.*, 1966; Getsen, 1975). However, the idea that carbonate sequences of the whole Timan Ridge and Kanin Peninsula are interrelated was proposed quite early by Volosovich (1944) and other geologists. Soon after the first publication, where carbonate formations of the middle and southern Timan previously described under different names were combined under the common name Bystraya Formation (Solntsev and Kushnareva, 1957), the idea of their unification was accepted by most researchers with

rare exceptions (Raznitsyn, 1964). The term "Bystraya Formation," first proposed by Kal'berg for the central Timan localities (Kal'berg and Vologdin, 1947), was deeply rooted in the literature. The less known term "Pav''yug Formation" (Nalivkin, 1962) was included in the aforementioned correlational scheme at the Conference on the Upper Precambrian in Syktyvkar (1983), because in the type region carbonate rocks do not entirely span the range of the Bystraya Formation and are sometimes distinguished as its lower member or subformation (Kal'berg, 1948), or as the Lower Bystraya Formation.

The similarity of "ancient algae" or "algal buildups" (Chochiya, 1955; Solntsev, 1959) and the stability of stromatolite and microphytolite assemblages (Zhuravlev *et al.*, 1966; Raaben and Zabrodin, 1972) in different regions of the Timan served as an important argument in favor of the unity of Bystraya sediments.

The composition of organic remains in Bystraya sediments always used to be the reference point when the question of the position of Timan Precambrian successions ("ancient formations," "M shales") in the general stratigraphic scale arose. These remains suggested an analogy with Hyperborean carbonate successions of Scandinavia and the Murmansk coast, or the so-called *Gymnosolen*-bearing beds, and/or with the Karatavian of the western Urals slope (Vologdin, 1938; Chochiya, 1955; Raaben, 1960; Krylov, 1960). The correlation with the Min'yar Formation suggested by Rostovtsev (1948), who studied sections in the southern Timan, Polyudov Ridge and Bashkir Upland, gained recognition since the moment when the similarity of the Bystraya and Min'yar phytolite assemblages was established (Raaben and Zabrodin, 1972).

Recently, the occurrence of one more ancient carbonate formation in the Riphean section of the Timan was reliably established. Possible analogues of the Katav Formation of the stratotype were recorded in deep excavations in the southernmost Timan (Rostovtsev, 1948; Vladimirskaya, 1955) and in wells of the western cis-Timan region (Kushnareva *et al.*, 1955). However, due to the absence of organic remains their age was interpreted controversially, and the validity of this unit was doubted (Chernaya, 1975). The carbonate succession with a stromatolite assemblage similar to the Katav and Demina assemblages, was distinguished by I.P. Chernaya based on the drilling records from the southern margin of the Chetlasskii Kamen' region and was called the Vorykva Formation (Chernaya *et al.*, 1979). In the type region this formation strongly differs from the Pav''yug (Bystraya) formation by both the

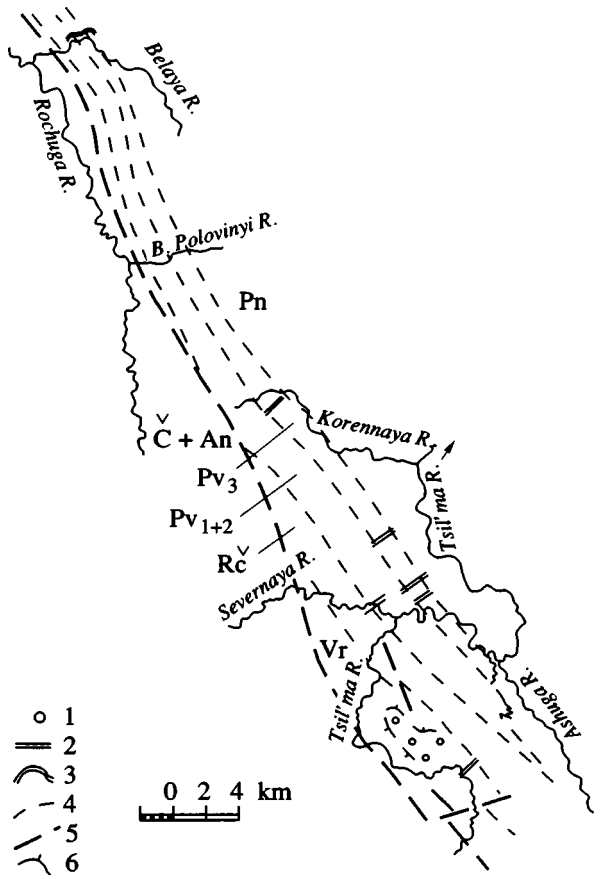


Fig. 1. Localities of collected paleontologic materials in the Tsil'ma and Rochuga river basins, northern Timan: (1) wells; (2) lines of well series; (3) outcrops (on the Belaya River); (4) boundaries of local lithostratigraphic subdivisions; (5) faults; (6) strike and dip of the Vorykva Formation.

Table 1. Correlation of Upper Riphean subdivisions of the Timan, Urals, and Polyudov Ridge in the correlation scheme of the Upper Precambrian in the North European USSR (*Rifei* ..., 1987, pp. 59–60). The Upper Riphean time-range is from 1050 ± 50 to 690 ± 25 Ma

Timan Ridge	Adjacent regions	
Chetlass-Tsil'ma Rampart	Urals	Urals foredeep
Paun Formation Pav''yug Formation	Min'yar Formation	Niz'va Formation
Rochuga Formation | Vorykva Formation	Podinzer beds ⟩ Inzer Formation	
	Katav Formation	Demina Formation
An'yug Formation	Zil'merdak Formation	Rassol'naya Formation

character of the rocks and the stromatolite composition. Like the Katav and Demina formations of the Urals, it is composed of variegated carbonate and clayey-carbonate rocks and includes biostromal layers with columnar stromatolites in its lower third. The formation consists of three parts with the lower member represented by brick-red limestones, the middle member of banded rose and greenish dolomites and marls, and the upper one composed of grey and greenish limestones and marls. In its structure it closely resembles the Katav Formation of the southern Urals in its western sections and differs only in that columnar stromatolite beds occur in the Urals not in these sections, but in eastern sections of the Inzer synclinorium and Yurezan' depression, where the Katav Formation lacks the three-membered structure (*Stratotip* ..., 1983). In the Vorykva Formation of the Chetlass uplift, as well as in the Katav and Demina formations, columnar stromatolites are represented by *Inzeria tjomusi* Kryl. and several *Jurusania* forms with the common *J. nizvensis* Raab. Stratiform stromatolites *Malginella*, distributed in the upper Katav Subformation (K-3), were not found in Vorykva sediments. However, in the Demina Formation malginelles are known only from thin members of sections in the Niz'va River and Polyudov Uplift, but they are absent in sequences of the Kolchim and Ukhtym uplifts.

In the southeast of the Chetlasskii Kamen' region, the Vorykva Formation is in contact with sediments of the Pav"yug Formation bearing here only the Min'yar stromatolite forms. The character of the contact between these formations remains unclear due to the lack of direct geologic data. Neither the more ancient age of the former, nor the correspondence of both to the Upper Riphean were disputed, though their relationships were differently interpreted, as was the correlation of the Vorykva Formation with type Karatavian sections of the Urals.

When distinguished, the Vorykva Formation was correlated with the Katav Formation of the stratotype, and this led to the assumption that there was a hiatus between this formation and the Bystraya stromatolite-bearing sequences spaning the interval of the Inzer Formation in the stratotype (Chernaya *et al.*, 1979). According to another interpretation included in the adopted correlation scheme, both formations compose a single succession of carbonate sediments (Plyakin, 1979; *Rifei* ..., 1987). Along with the widely accepted analogy between the Bystraya (Pav"yug) and Min'yar formations, this interpretation caused a correlation of the Vorykva Formation with the wide interval of the Karatau Group in the southern Urals, as well as with the Demina and two lower subformations of the Niz'va Formation of the Polyudov Ridge (*Rifei* ..., 1987), in other words, with the combined Yurezan' and Sim horizons (*Stratotip* ..., 1983). The idea of a continuous succession was supported by the data on the occurrence of a gradual transition between the Pav"yug Formation and the shaly-carbonate Rochuga Formation in the Rochuga River basin, Tsil'men' Kamen' region (Getsen, 1975). The latter subdivision is considered as a lateral analogue of the Vorykva Formation (*Rifei* ..., 1987).

As indicated below, the new data on the Tsil'ma uplift mainly agree with the adopted interpretation of the relationships between the Vorykva, Rochuga, and Pav"yug formations. However they pose in a different way the question of their time-range and correlation with Karatavian type sections of the Urals.

The Vorykva Formation, more than 300 m thick, forms a stripe of south-southeastern to north-northwestern direction in the upper reach of the Tsil'ma River and is overlain by Devonian deposits in the main distribution area. Southward of the Severnaya River its sediments form an anticline dipping to the north-northwest and disrupted by a cross fault in the south. The base of the formation was not recovered in the Tsil'menskii Kamen' region; in the west it has a tectonic contact with older sediments of the An'yug Formation and Chetlass Group. The Vorykva Formation is largely composed of carbonate rocks, namely, of limestones and dolomites colored from light greenish-grey, almost white, to dark grey and brown, and enclosing rare beds of carbonate shales. Stromatolite rocks occur among dolomites sometimes accompanied by conglobreccia. Near the base of the recovered section some problematic structures were recorded. They are similar to passively branching stromatolites, but evidently correspond to almost reliefless mats with narrow erosion channels. Somewhat upward the section the stratiform stromatolites *Stratifera pseudocolumnata* Komar, domelike constructions of *Paniscollenia* sp., and fragments of *Baicalia* (?) columns were encountered. In the middle part of the section two stromatolite beds were traced in the eastern and western flanks of the anticline. The lower bed, 10 m thick, is composed of *Kussiella* aff. *timanica* Raab. columns, whereas the upper one, 12 m thick, occurs 45–50 m upward the section and includes *Jurusania nizvensis* var. *kurtuniformis*. The stromatolite rocks are accompanied by carbonate conglobreccia.

The variety *J. nizvensis* var. *kurtuniformis* (nov.) retains all features of the formal species, namely, the amorphous-pellicular lamellar structure of layers, small column dimensions, their frequent deviation from the cylindrical form, and an abundance of connective bridges. It is characterized by the predominance of elongated columns with stretched cross-sections. In this peculiarity it resembles the Siberian Upper Riphean *Kurtunia longa* Schenfil, which is reflected in the variety name.

Stromatolites are missing in the upper 100–150 m of the Vorykva Formation. Its upper boundary was not recorded in the Tsil'ma River basin; there are also no direct geologic data on the unit relationship with the Rochuga Formation, which is adjacent to it from the east and has the same east-northeast dipping.

The siliciclastic–carbonate Rochuga Formation in its type region, on the right bank of the Rochuga River, contacts along the fault with sediments of the Chetlass Group. The Rochuga sediments exposed along the Rochuga tributaries, namely, the Belaya River and Bol'shoi and Malyi Polovinnyi creeks, are 300–400 m thick. The lower half of the succession is formed by variegated laminated shales consisting of carbonate, sericite, chlorite, and hydromica, and alternates with thin limestone and dolomite beds. The upper half of the formation is mainly represented by dark- and greenish-grey shales of the same composition with thin siltstone beds and separate dolomite members, which contain layers of carbonaceous shales (Getsen, 1975). In the Tsil'ma River basin, the Rochuga sediments are also represented by dark-colored, grey, and greenish sericite–chlorite and quartz–sericite–chlorite shales with rare thin siltstone beds and carbonate members. The Tsil'ma River well near the Severnaya River mouth recovered a bed (lens?) of stromatolite dolomites and carbonate conglobreccia about 10 m thick, which occurs 100 m below the top of the Rochuga Formation. Stromatolites are represented by *J. nizvensis* var. *kurtuniformis,* and occurence of this form favors the idea of the lateral substitution of Vorykva carbonate rocks by Rochuga shaly carbonate sediments that is adopted in the correlation scheme. However, it does not prove that the substitution takes place in the complete range of two formations.

The Pav"yug (Bystraya, Lower Bystraya) Formation consists almost completely of carbonate rocks 1000 m thick, and its exposures stretch as a continuous stripe from the left bank of the Rochuga River to the watershed between the Tsil'ma River and its tributary Ashuga River, i.e., from the north-northwest to south-southeast. It is exposed there better than along the Pav"yug and Belaya rivers and in other sections of the Chetlasskii Kamen' region, where outcrops are fragmentary and display tectonic contacts between this and other formations. On the Tsil'ma uplift the conformable gradational contact between the Pav"yug and underlying Rochuga formations is evident in the Tsil'ma River localities, where it was recovered by wells near the Severnaya River mouth. As indicated above, the same relationship was recorded in the Rochuga River basin.

In the Tsil'ma River basin, to the north of the Ashuga River, the Pav"yug Formation includes three subformations. The lower Pav"yug Subformation, 200–250 m thick, is composed of limestones and dolomites with numerous stromatolite members. Its basal part contains a thick (40–50 m) member of dark grey, almost black stromatolite dolomites with carbonaceous shale beds. Biostroms of *Conophyton garganicus* var. *ikeni* Raab. et Kom. sometimes associated with *Colonella* sp. constitute the dolomite beds. The middle part of the lower subformation is represented by grey dolomites with *Baicalia* ex gr. *prima* Semikh. and *B.* cf. *lacera* Semikh. The upper portion of the subformation is light grey to yellow and yields *Poludia mutabilis* Raab. et Komar (Fig. 2).

The middle Pav"yug Subformation, 300–350 m thick, is barren of stromatolites. It is composed of bluish and grey bedded limestones and dolomites mainly without organic remains; small *Vesicularites* occur only in the upper part.

The upper Pav"yug Subformation, 450–500 m thick, has a considerable proportion of biohermal stromatolite rocks and is often called the biohermal unit. It is formed by massive grey, yellow-brown, and reddish dolomites. Along with strongly predominant stromatolite rocks, the carbonate breccias, oncolitic dolomite layers, and separate members of bedded carbonates occur in places.

The rocks of this subformation yield the following diverse stromatolite set: *Gymnosolen giganteus* Raab., *G. ramsayi* Steinm, *G. levis* Kryl., *G. asymmetricus* Raab., *Minjaria* sp., *Inzeria* cf. *djejimi* Raab., *Parmites nubilosus* Raab. et Komar, *P. concrescens* Raab., *Tungussia perforata* Raab., *Poludia polymorpha* Raab., and nonidentified forms of *Tungussia, Parmites*, and *Poludia*. According to previously cited data, deposits on the Severnaya River contain *Con. miloradovicĭ* Raab. as well (*Rifei* ..., 1987). Rare microphytolites are represented by *Vesicularites* sp.

Data available from wells on the Tsil'ma River, downstream of the Severnaya River mouth, illustrate the succession of some stromatolite forms in the section. For instance, *Gymnosolen giganteus* and *G. ramsayi* occur in the basal part of the subformation, *Poludia polymorpha* and similar forms together with *Parmites nubilosus* and *Parmites* sp. dominate in the middle part, whereas upper beds contain *Poludia concrescens* and *Gymnosolen levis*.

The upper Pav"yug Subformation is also recorded as a unit of predominantly biohermal stromatolite rocks in northern sections of the Rochuga River basin. In outcrops along the Belaya River its basal part is composed of massive grey and yellowish dolomites with *Gymnosolen giganteus,* above which, as in the Tsil'ma River basin, beds with abundant *Poludia polymorpha* and *Poludia* sp. are well represented. In the Rochuga River basin the lower and middle subformations are not divided, because stromatolite-free beds in the middle part of the section are absent here (see also *Rifei* ..., 1987, Fig. 21). Near the base of the formation, as on the Tsil'ma River, a characteristic member of dark-colored dolomites with carbonaceous shale beds was recorded.

The Pav"yug Formation is overlain by the shaly Paun Formation, the upper subdivision of the Riphean in the scheme of 1985–1987. According to the scheme, its thickness is 1000–1500 m, yet by other estimates it varies from 600 to 2500 m. The Paun Formation was distinguished in the Svetlaya River basin of the Chetlass uplift (Nalivkin, 1962). Its stratotype on the Paun Creek is a part of the type section of the Bystraya Formation, and the Paun Formation coincides there with

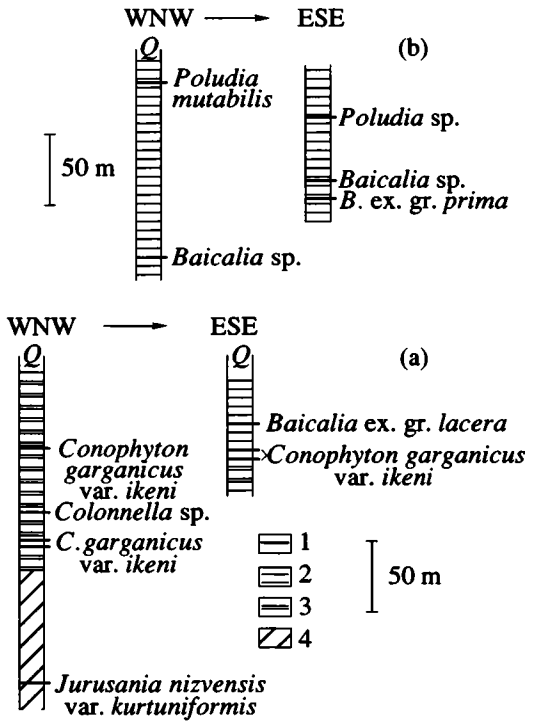


Fig. 2. Stromatolite vertical distribution in sections of the reference well group near the Severnaya River mouth, Tsil'ma basin. 1, levels with stromatolites; 2–4, enclosing rocks (2, 3, Lower Pav"yug Subformation): 2, dolomites, stromatolite dolomites; 3, black stromatolite dolomites with members of carbonaceous-carbonate shales; 4, Rochuga Formation, shales with siltstone beds and carbonate members.

the upper Bystraya (=Oselok=shaly) Subformation of the Kal'berg's scheme (1948).[1] It is represented by dark- and steel-grey quartz-sericite and sericite shales with isolated thin dolomite and limestone beds. Due to the poorly exposed type and some other sections, the Paun Formation range and its relationships with other Precambrian lithostratigraphic subdivisions were variously interpreted. For example, Getsen (1975) included the Paun Formation in the Kislyi Ruchei complex and suggested that it contacts everywhere with the Pav"yug Formation along the fault and is a constituent of another structural zone. More recently, the opinion that the Paun Formation conformably overlies the Pav"yug formation was reflected as prevailing in the correlation scheme of 1985–1987. However, previously many geologists following Kal'berg suggested the possibility of lateral substitution between the carbonate and Oselok subformations of the Bystraya Formation, that is, between the Pav"yug and Paun formations (Zhuravlev and Osadchuk, 1963; Zhuravlev *et al.*, 1966). They also believed that the carbonate rock thickness decreases and stromatolite dolomites disappear from the section as the shale thickness in the Chetlasskii Kamen' region concurrently increases from the south-southeast to north-northwest.

Changes of this sort but in the opposite, north-northwest to south-southeast, direction were recorded in the Tsil'ma River basin. In the area extending from the Belaya River to the Ashuga River mouth, the Paun Formation is subdivided into three members. The upper and lower ones are considerably shaly, whereas the middle member is composed of siltstones, shales, and sandstones. The lower member of dark-colored carbonate-clayey carbonaceous shales overlies stromatolite rocks of the upper Pav"yug Subformation usually without visible unconformity. In the lower reach of the Ashuga River stromatolite-bearing upper Pav"yug rocks are missing. The Paun Formation replacing them consists here of dark-colored quartz-chlorite-sericite shales, overlies rocks of the middle Pav"yug Subformation, and encloses layers and large members of carbonate rocks up to 70 m thick. In the upper reaches of the Ashuga River and further southwards, the Pav"yug Formation is absent, while the distribution areas of Paun and Rochuga shale units join. These relationships again suggest a lateral transition between the Pav"yug and Paun formations. The transition is all the more probable as the accumulation of carbonate rocks of the former formation is commonly considered to take place in reef settings.

At the same time, there is the question whether or not the younger sediments are also incorporated into the Paun Formation in addition to lateral stratigraphic analogues of the Pav"yug Formation. Traces of an unconformity at the base of the lower shaly member of the Paun Formation northward from the Ashuga River, and the fact that at the Och-Parma its section begins with conglomerates above the conformable boundary (Getsen, 1975) indicate such a possibility. To test these assumptions, one should extend the investigations of detailed lithostratigraphy of Paun sediments and biostratigraphy of the Pav"yug Formation outside the studied region. We touch on these questions here in a preliminary way. We do not yet have paleontologic data that could shed light on the stratigraphy of the Paun Formation. The stromatolite rocks are missing or extremely rare within it. In its distribution area on the Korennaya River Raaben found blocks of stromatolite dolomites with *Poludia polymorpha,* but their position in the section is not certain and more reliable data remain to be found.

Turning back to stromatolite sequences of the Tsil'menskii Kamen' region, we stress that it shows a succession of Vorykva (Vorykva-Rochuga) assemblages (beds 1 and 2) and all stromatolite beds from different levels of the Pav"yug Formation. From the base upward the succession includes: (3) beds with *Con. garganicus* var. *ikeni* and colonnelles; (4) beds with *Baicalia* pl. sp.; (5) beds with *Poludia mutabilis* and the upper Pav"yug polyspecific assemblage, which can be subdivided into beds with (6) *Gymnosolen giganteus*

[1] Paun, Bystraya, and Bystrukha are synonyms of the same river.

Table 2. Correlation of Upper Riphean stromatolite-bearing formations of the Timan and Urals with regard to the new data. Figures in columns are stromatolite beds

Timan, formations		Polyudov Ridge, formations		Southern Urals		
				formations		horizons
?				Uk	12 11	Uk
Paun	9 8 7		8 7	Min'yar	10 9 8 7	Suleimanovo
Pav''yug	6 5	Niz'va	6 5	Inzer	6 5	Minka
	4 3			Sim	4 3	Sim
Rochuga Vorykva	1, 2	Demina	2 1	Katav	2 1	Yurezan'
An'yug		Rassol'naya		Zil'merdak		

and *G. ramsayi;* (7) with *Poludia polymorpha* and *Parmites nubilosus;* and (8, 9) with *Parmites concrescens* and *Gymnosolen levis* (Table 2).

In other Timan uplifts this succession is known in fragments only. The lower part of the stromatolite succession is well represented in the Chetlasskii Kamen' region. The combination of *Inzeria tjomusi* Kryl. and *Jurusania* pl. sp. is typical of the Lower Karatavian of northern Eurasia, both in the Urals and Eastern Siberia (Semikhatov and Raaben, 1993), whereas the occurrence of *J. nizvensis* intercorrelates the Vorykva assemblages in the Chetlass and Tsil'ma uplifts. The comparison of their composition in these regions shows that the southern assemblage is richer in columnar forms but less diverse in morphotypes. Stratiform and nodular stromatolites, which occur only in the Tsil'ma uplift, are usually considered as markers of shallow-water environments, and just these environmental peculiarities most likely were responsible for differences mentioned above. The Pav"yug Formation in the Chetlasskii Kamen' region contains only forms of the upper Pav"yug stromatolite assemblage, namely, *Gymnosolen asymmetricus, Inzeria djejimi*, and *Parmites* sp.

In the southern Timan, the Pav"yug Formation is the only carbonate unit. At the Och-Parma locality, the rocks of its lower half yield *Tungussia colčimi.* The upper half of the formation at this locality and its entire visible section at the Dzhezhim-Parma chiefly consist of stromatolite dolomites bearing taxa common with the upper Pav"yug assemblage from the Tsil'ma region, namely, *Gymnosolen giganteus, Conophyton miloradovići, Inzeria djejimi, Poludia polymorpha,* and *Parmites concrescens.* At the Dzhezhim Parma they are followed by some endemics. The succession of common forms is like that from the Tsil'ma River basin.

Investigations on the Tsil'ma uplift extended the data on stromatolite taxonomic composition from lower and upper parts of the Karatavian carbonate succession of the Timan and filled a gap in the stromatolite characteristics of the intermediate part of the section. As a result the number of taxa known from the Upper Riphean sediments of the Timan Ridge substantially increased. Currently the list includes 14 genera and 22 forms. Over 90% of genera and about 80% of species are common with taxa from the Uralian Karatau Group and occur either in both the Bashkiriya anticlinorium and Polyudov Ridge, or in one of these regions. Accordingly, there is no doubt that the Timan and western slope of the Urals belong to a single stromatolite province. Therefore, within its limits the common taxa and similar assemblages provide a reliable basis for detailed stratigraphic correlation.

Analogues composition and the succession of taxa strongly suggest the correlation of the Katav and Demina formations with the pre-Pav"yug part of the stromatolite succession from the northern and middle Timan despite the fact that upper portions of the Vorykva and Rochuga formations are barren of stromatolites. Actually, basal beds of the Pav"yug Formation with *Conophyton garganicus* var. *ikeni* followed by *Colonnella*, found in the Tsil'ma uplift of Timan for the first time, are similar to the beds that mark the base of the Sim Formation in the Uralian stratotype of the Karatau Group. Above them there are beds with *Baicalia* ex gr. *prima*, which in the Urals occupy a place near the top of the Sim Formation. The complex of cited taxa is characteristic of the Sim Horizon of the Lower

Karatavian (*Stratotip* ..., 1983; Keller and Raaben, 1989).

Stromatolites of the Min'yar assemblage appear in the Tsil'ma River basin below the base of the second (stromatolite-free) unit. Its representatives *Poludia mutabilis* and *Tungussia colčimi* are constituents of the more diverse tungusside assemblage of the Urals, which characterizes the lower part of the Minka Subformation and the horizon of the same name. In the Polyudov Ridge *T. colčimi* another component of this assemblage, is known from subformation II of the Niz'va Formation (Raaben and Zabrodin, 1972). Besides it also occurs in the basal part of the recovered section of the Pav"yug Formation at the Och-Parma. *Gymnosolen giganteus,* the most important form among stromatolites from lower beds of the upper Pav"yug Formation, is not represented in the stratotype, but biohermal beds with this species have their analogues in the Polyudov Ridge: they form the lower part of subformation III of the Niz'va Formation, are overlain by beds with *Conophyton miloradoviči,* and their top marks the boundary between the Minka and Suleimanovo horizons (Keller and Raaben, 1989). The major part of forms from the upper Pav"yug assemblage of the Tsil'menskii Kamen' region occurs in the B'yanka Subformation of the Bashkir anticlinorium. To the taxa mentioned above, previously known and widespread in the Timan and Polyudov Ridge, we add typical southern Uralian *Tungussia perforata, Parmites nubilosus,* and *Gymnosolen levis.*

If these correlations are correct, the Vorykva–Rochuga interval corresponds only to the Katav Formation of the stratotype and to the Demina Formation of the Polyudov Ridge, whereas the Pav"yug Formation of the Tsil'ma uplift has a wider time-range. It is similar to the Niz'va Formation of the Polyudov Ridge, and corresponds to the interval incorporating the Sim, Inzer, and most of the Min'yar formations of the stratotype. Analogues of the uppermost beds of the Karatau Group are missing in the Tsil'ma and other uplifts of Timan, at least in carbonate facies. Beds with abundant *Minjaria* and other forms from the Shubino Member and Uk Formation were not found in these sections (beds 10, 12, Table 2).

It turns out that the Min'yar assemblage of stromatolites, which is widespread in the Timan sections and was previously referred to the whole Pav"yug Formation (e.g. Raaben, 1987), is characteristic only of its upper part. The absence of beds with older forms in most sections can reflect some peculiarities of the Tsil'ma uplift. One such peculiarity is the lateral instability of carbonate units exposed in individual sections. The time-range of the Upper Riphean carbonate members of the northern and middle Timan substantially varies due to their substitution by shaly rocks. One more possible factor is the discontinuous distribution of the proper stromatolite beds within the carbonate sequences. These beds are laterally substituted by unfossiliferous bedded rocks as occurs in the middle part of the Pav"yug Formation between the Rochuga and Tsil'ma river basins.

However, one should take into account that the absence of other than Min'yar stromatolite beds in certain Timan sections can be only an illusion. It will suffice to recall that *Jurusania* and *Inzeria* beds of the Yurezan' Horizon were first discovered by drilling in the Chetlasskii Kamen' region. The same happened recently in the Tsil'menskii Kamen' in respect to *Conophyton* and *Baicalia* beds of the Sim Horizon. As before, only beds bearing the Min'yar stromatolite assemblage are known in the best outcrops of the Rochuga River basin. We would need materials at least as complete as those available for the Tsil'ma uplift in order to evaluate the character of sections in other Timanian structures and to reconstruct general relationships between different Upper Riphean sedimentary facies of the Timan.

Reviewers Yu.R. Bekker and M.A. Semikhatov

REFERENCES

Chernaya, I.P., On Lithology of the Carbonate Sequence in the Western Structural-Formation Zone of the Timan, in *Geologiya i poleznye iskopaemye Timano-Pecherskoi provintsii* (Geology and Mineral Deposits of the Timan-Pechora Province), Syktyvkar: Komi Kn. Izd., 1975, pp. 19–25.

Chernaya, I.P., Chernyi, V.G., and Raaben, M.E., Major Problems of the Upper Riphean and Vendian Stratigraphy of the Timan, in *Stratigrafiya verkhnego proterozoya SSSR (rifei i vend)* (Upper Proterozoic Stratigraphy of the USSR. Riphean and Vendian), Leningrad: Nauka, 1979, pp. 102–107.

Chochiya, N.G., Geologic Structure of the Kolva and Vishera Region, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst., Nov. ser.,* 1955, vol. 91.

Getsen, V.G., *Stroenie fundamenta Severnogo Timana i poluostrova Kanin* (The Basement Structure of Northern Timan and Kanin Peninsula), Leningrad: Nauka, 1975.

Ivensen, Yu.P., *Magmatizm Timana i poluostrova Kanin* (Magmatism of the Timan and Kanin Peninsula), Moscow: Nauka, 1964.

Kal'berg, E.A., New Data on the Stratigraphy and Tectonics of the Central Timan, *Sov. Geol.*, 1948, no. 33, pp. 33–40.

Kal'berg, E.A. and Vologdin, A.G., On the Age of the Timan Metamorphic Sequence, *Dokl. Akad. Nauk SSSR,* 1947, vol. 58, no. 1, pp. 1640–1642.

Keller, B.M. and Raaben, M.E., Horizons of the Upper Precambrian, in *Problemy stratigrafii verkhnego proterozoya i fanerozoya* (Problems of the Upper Proterozoic and Phanerozoic Stratigraphy), Moscow: Nauka, 1989, pp. 6–12.

Krylov, I.N., On Significance of *Collenia buriatica* Stromatolites for the Upper Precambrian Stratigraphy of Russian Platform Margins, in *Stratigrafiya pozdnego dokembriya i kembriya* (Late Precambrian and Cambrian Stratigraphy), Moscow: Akad. Nauk SSSR, 1960, pp. 131–139.

Kushnareva, T.N., Zhuravlev, V.S., Zarkh, V.P., and Saar, A.A., On the basement Stratigraphy and Tectonics of the South-

western Timan Region, *Dokl. Akad. Nauk SSSR,* 1965, vol. 162, no. 5, pp. 632–635.

Miloradovich, B.V., Geologic Structure of the Dzhezhim Parma, Southern Timan, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst., Ser. A,* 1938, vol. 53.

Nalivkin, A.B., On Stratigraphy and Tectonics of the Timan Metamorphic Sequence, *Trudy Soveshchaniya po utochneniyu unifitsirovannykh stratigraficheskikh skhem paleozoya Volgo-Ural'skoi neftyanoi provintsii* (Proc. Conf. on the Refinement of Unified Paleozoic Stratigraphic Schemes of the Volga–Ural Oil Province), Moscow, 1962, pp. 122–123.

Plyakin, A.M., Some Problems of the Precambrian Stratigraphy in Timan, in *Stratigrafiya verkhnego proterozoya SSSR (rifei i vend)* (Upper Proterozoic Stratigraphy of the USSR. Riphean and Vendian), Leningrad: Nauka, 1979, pp. 109–111.

Raaben, M.E., Stratigraphic Significance of *Gymnosolen* Beds, in *Stratigrafiya pozdnego dokembriya i kembriya* (Late Precambrian and Cambrian Stratigraphy), Moscow: Akad. Nauk SSSR, 1960, pp. 125–131.

Raaben, M.E., Phytolites in the Upper Precambrian of the North European Part of the USSR, in *Rifei i vend Evropeiskogo severa SSSR* (Riphean and Vendian of the North European Part of the USSR), Syktyvkar: Komi Fil. Akad. Nauk SSSR, 1987, pp. 34–40.

Raaben, M.E. and Zabrodin, V.E., *Vodoroslevaya problematika verkhnego rifeya* (Upper Riphean Problematic Algal), Moscow: Nauka, 1972.

Raznitsyn, V.N., *Tektonika Yuzhnogo Timana* (Tectonics of the Southern Timan), Moscow: Nauka, 1964.

Rifei i vend Evropeiskogo severa SSSR (Riphean and Vendian of the North European Part of the USSR), Dedeev, V.A. and Getsen, V.G., Eds., Syktyvkar: Komi Fil. Akad. Nauk SSSR, 1987.

Rostovtsev, N.N., The Upper Paleozoic–Riphean Section of Northwestern Kel'tmen Rampart, *Sov. Geol.*, 1948, no. 28, pp. 16–31.

Semikhatov, M.A. and Raaben, M.E., Dynamics of Taxonomic Diversity of Riphean and Vendian Stromatolites in Northern Eurasia, *Stratigr. Geol. Korelyatsiya,* 1993, vol. 1, no. 2, pp. 3–12.

Solntsev, O.A., Metamorphic Shales, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst.,* 1959, vol. 133, pp. 5–18.

Solntsev, O.A. and Kushnareva, T.N., The Timan–Pechora Province, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst.,* 1957, vol. 101, pp. 5–48.

Stratotip rifeya. Stratigrafiya. Geokhronologiya (Riphean Stratotype. Stratigraphy. Geochronology), Keller, B.M. and Chumakov, N.M., Eds., Moscow: Nauka, 1983.

Vladimirskaya, E.V., Pre-Devonian Sediments of the Kolva–Vishera Region, *Tr. Vses. Nauch.-Issled. Geol.-Razved. Inst.,* 1955, vol. 90, pp. 225–280.

Vologdin, A.G., New Turukhansk Oil Field, *Sov. Geol.,* 1938, no. 12, pp. 3–13.

Volosovich, K.K., *Ob"yasnitel'naya zapiska k listu R-38 (Syktyvkar) geologicheskoi karty SSSR* (Explanatory Notes for the Geologic Map of the USSR, Sheet R-38, Syktyvkar), Moscow: Gosgeolizdat, 1944.

Zhuravlev, V.S. and Osadchuk, M.I., The Timan Ridge and Kanin Peninsula, in *Verkhnii dokembrii* (Upper Precambrian), Moscow: Gosnauchtekhizdat, 1963, pp. 206–238.

Zhuravlev, V.S., Zabrodin, V.E., Raaben, M.E., and Chernyi, V.G., On the Basement Stratigraphy of the Timan Ridge, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1966, vol. 41, no. 2, pp. 49–75.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 118–125. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 21–28.
Original Russian Text Copyright © 1997 by Rodionova, Umnova.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Fluctuations of Devonian Sea Level in the Moscow Basin

G. D. Rodionova and V. T. Umnova†

Center of Regional Geology, Varshavskoe sh. 39-a, Moscow, 113105 Russia

Received December 18, 1994

Abstract—A representative data base is used to elucidate the history of Devonian sedimentation in the Moscow basin of the Russian platform. The Devonian section includes six rhythms of sedimentation and seven principal geological boundaries, whose levels are identified on the basis of miospore, brachiopod, and conodont zonation. The inferred curve of secular variations in the basin salinity is plotted versus palynological and standard conodont zones and correlated with the main stages of sedimentation and sporgenous plant evolution. There is also a positive correlation between the salinity variation in the Devonian Moscow basin and global eustatic events detected by Johnson and Sandberg.

Key words: *Devonian, Moscow basin, sedimentation, miospores, conodonts, brachiopods.*

In this work, we consider the Moscow sedimentary basin as representing a shallow epicontinental Devonian sea of variable salinity, which occupied the Moscow syneclise and adjacent southward slopes of the Voronezh anteclise (Fig. 1). Sedimentary facies of the basin were deposited in open marine, lagoonal, and littoral settings. In the larger part of the area under consideration, they are deeply buried under younger deposits. Their thickness is up to 900–1000 m in the deep central zone of the syneclise and decreases down to 150–200 m on the Voronezh anteclise slopes.

The rhythmic sedimentation represents a characteristic feature of Devonian deposits. Each rhythm lasted from the expansion to contraction phase of the marine sedimentation area (Tikhomirov, 1967). The ranges of these transgressive–regressive rhythms of various rank may correspond to separate units of the stratigraphic scale (Fig. 5).

In this study of Devonian deposits, we widely used the palynological method suitable for correlation of synchronous deposits, when they are represented by different facies, such as normal marine, saline lagoonal, and some littoral sediments. Vertical distribution patterns of guide spore forms and assemblages positively suit the recent data on stages and turning points in the history of Devonian sedimentation (Rodionova *et al.*, 1995). They are supplemented with data on brachiopods and conodonts, whose occurrences are restricted, as usual, by the normal marine facies.

In 1993, one of us (Rodionova) composed lithofacies maps and cross sections for several horizons (Figs. 2–4) using data from more than 1000 drill holes and exposures. In this work, these materials are used to plot the conditional curve of sea-level fluctuations in the Devonian Moscow basin (Fig. 5). The curve is based on estimated ratios (in percents) between the marine facies of normal salinity and the total area of the basin. We assume that these facies correspond to calcareous-clay and carbonate deposits bearing brachiopods, ostracodes, conodonts, gastropods, echinoderms, bryozoans, and corals.

Miospores, their zonation, and stages in evolution of sporgenous plants were studied by V.T. Umnova. Distribution of brachiopods was analyzed by M.A. Rzhon-

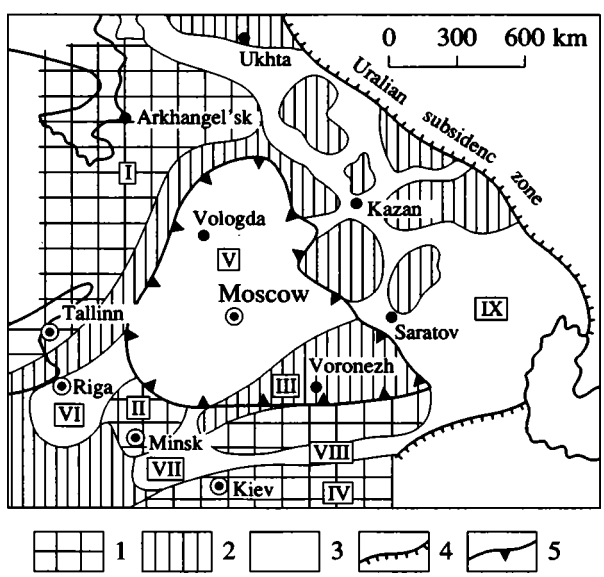


Fig. 1. Paleotectonic scheme of the Russian platform at the Devonian time: (1) uplifts; (2) uplifts alternating with subsidence zones; (3) subsidence areas; (4) boundaries of the platform; (5) boundaries of the Moscow basin; (I) Baltic Shield; (II) Belarussian anteclise; (III) Voronezh anteclise; (IV) Ukrainian Shield; (V) Moscow syneclise; (VI) Lithuania–Latvia syneclise; (VII) Pripyat' depression; (VIII) Dnieper–Donets depression; (IX) Caspian depression.

† Deceased.

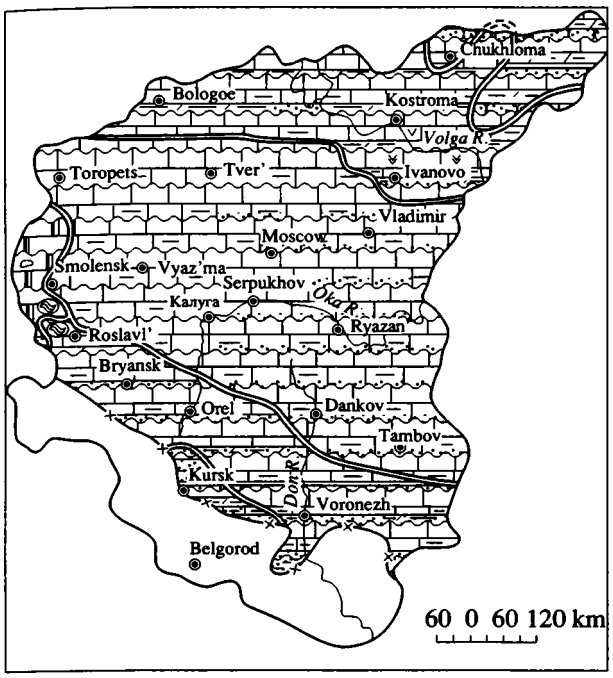


Fig. 2. Map of Sargaevo Horizon facies (Frasnian Stage) in the central Russian platform occupied by sea water of normal salinity (see Fig. 3 for symbols).

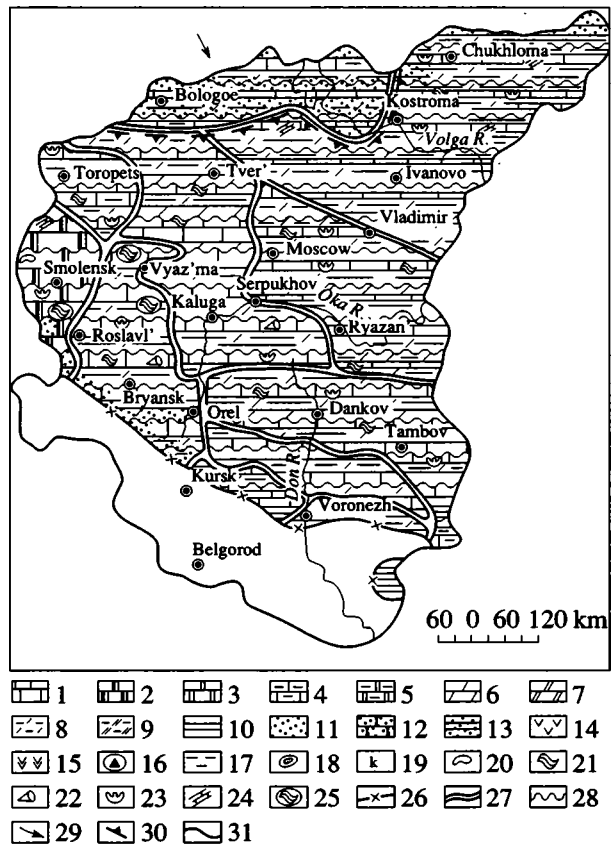


Fig. 3. Map of Semiluki Horizon facies (Frasnian Stage) in the central Russian platform occupied by sea water of normal salinity aside from the northwestern area: (1) limestone; (2) metasomatic dolomite; (3) sedimentary fine-grained dolomite; (4) clayey limestone; (5) clayey dolomite; (6) limy marl; (7) dolomitic marl; (8) calcareous clay; (9) dolomitic clay; (10) carbonate-free clay; (11) sand; (12) sandstone and siltstone; (13) clay and shaly clay; (14) layered gypsum and gypsum admixture; (15) anhydrite; (16) basalt; (17) clay admixture; (18) ferrugenous oolites; (19) variegated rocks; (20) vuggy rocks; (21) stromatoporoids; (22) solitary corals; (23) colonial corals; (24) bryozoans; (25) coral-stromatoporoid reefs; (26) distribution boundary of the horizon; (27) facies boundary; (28) distribution boundary of type sections; (29) directed influx of clastic material; (30) distribution boundary of normal marine facies; (31) boundary of the basin.

snitskaya. Our scheme of local brachiopod and conodont zones, as well as their correlation with the standard scale, is based on the regional stratigraphic scheme accepted for the Russian platform (*Reshenie ...*, 1990) and on some supplementary materials (Rzhonsnitskaya and Kulikova, 1991).

The Lower Devonian deposits are of a very limited occurrence in the region. Recently, Umnova and Rodionova (1991) reported on several finds of Early Devonian spores of the *Emphanisporites minutus–E. protophanus* assemblage, which were recovered from beds underlying the Ryazhsk Horizon (the lower part of the Lokhkov regional stage). At present, it is impossible to outline the distribution area of these beds. The section of Devonian deposits, whose age is well substantiated by fauna, begins in the Moscow basin from the upper Emsian level.

The Emsian–Eifelian stage of sedimentation comprises the Ryazhsk–Dorogobuzh and Klintsy–Chernyi Yar rhythms. Sediments of the lower rhythm are represented by terrigenous sand, sandstone, siltstone, and clay at the base (Ryazhsk Horizon), and by halide–sulfate deposits in the upper portion (Dorogobuzh Horizon). Rare and poorly preserved organic remains from these rocks include fish fragments, ostracodes, lingulids, coalified plant detritus, and spores. The dominant spores of the *Retusotriletes* Naum. subgroup are typical of the *Retusotriletes clandestinus–Diaphanospora inassueta–Elenisporites biformis* sequence of palynozones. The transgressive maximum in the Klintsy–Chernyi Yar sedimentary rhythm corresponds to the Mosolovo Horizon. The rhythm mainly consists of marine clay–carbonate deposits bearing diverse assemblages of brachiopods and ostracodes associated with bivalves, gastropods, crinoids, bryozoans, trilobites, and fishes. This interval is subdivided into local *Plicoproductus nibelia–Spinatrypa mosolovica* (Klintsy Horizon), and *Variatrypa sokolovae* (Chernyi Yar Horizon) zones. Spores enable identification of the *Grandispora naumovii* (*Hymenozonotriletes naumovii*) and *Rhabdosporites langii* palynozones as corresponding to the Klintsy and coupled Mosolovo and Chernyi Yar horizons, respectively. On the basis of conodont fauna, deposits of the rhythm were described as *Polygnathus parawebbi* Beds (Aristov, 1988) apparently cor-

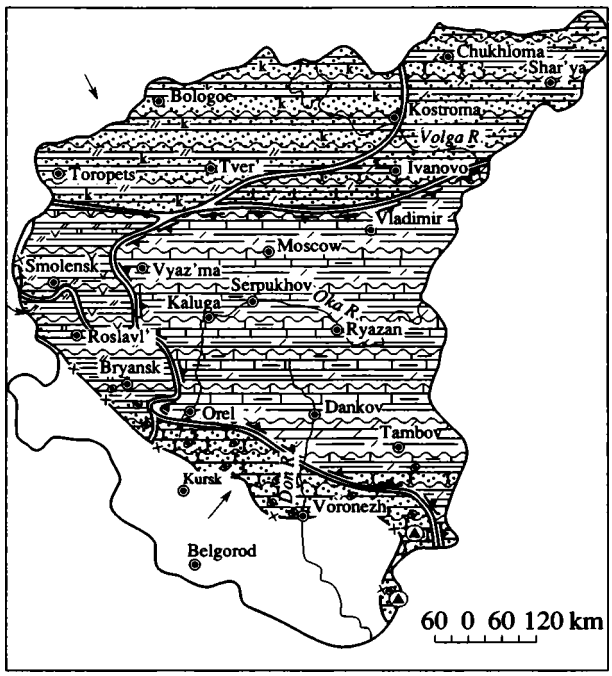


Fig. 4. Map of Petino Horizon facies (Frasnian Stage) in the central Russian platform; only the eastern part of the region is occupied by sea water of normal salinity (see Fig. 3 for symbols).

responding to the *australis–kockelianus* and, perhaps, *costatus* zones of the standard scale (data of N.S. Ovnatanova and L.I. Kononova). The Emsian–Eifelian deposits transgressively overlie either older strata of different age, or the crystalline basement of the Voronezh anteclise. The northern part of the region near Chukhloma displays basaltic eruptions of the Ryazhsk time. We classify the base of the Ryazhsk Horizon as the natural geological boundary (I).

The Givetian stage of sedimentation corresponds to the Vorob'evka, Ardatovka, and Mullino horizons, the constituent units of the Staryi Oskol Superhorizon. In the Moscow basin, this superhorizon is composed of terrigenous clay, sand, sandstone, and siltstone. All these gray or variegated deposits are rich in mica and rhythmical in structure. Their organic remains are mostly represented by spores of the *Geminospora extensa* (*Archaeozonotriletes extensus*) Zone. On the slopes of the Voronezh anteclise, the shallow-water clay–carbonate deposits of the Staryi Oskol Superhorizon bear brachiopods, ostracodes, and conodonts. Their brachiopod assemblage is typical of the *Stringocephalus burtini* Zone. According to conodonts, the deposits were identified as the *Icriodus difficilis* Beds (Aristov, 1988) compatible with the *varcus* Zone of the standard conodont zonation. The Givetian (Staryi Oskol) deposits usually overlie different levels of the Chernyi Yar Horizon and locally, e.g., on the southeastern slope of the Voronezh anteclise, rest on rocks of the Mosolovo Horizon. Fracture zones of the anteclise, which were activated at the Vorob'evka time, served as conduits for basaltic extrusions. The level separating Eifelian and Givetian stages represents the natural geological boundary (II).

The lower Frasnian deposits span, as follows from the regional stratigraphic scale (*Reshenie ...*, 1990), the Arkhangel-Pasha and Timan horizons distinguished in the Komi Superhorizon. In the Moscow basin, this superhorizon consists of clay, silt, sand, siltstone, and sandstone. These frequently variegated and micaceous rocks enclose abundant plant remains, lingulids, phyllopods, fish bones, and rare spores, such as *Archaeozonotriletes micromanifestus* Naum. and *Hymenozonotriletes incisus* Naum. In the Voronezh anteclise, the Arkhangel-Pasha Horizon is of a similar sandy-clayey composition; however, the overlying Timan Horizon includes here marl and limestone interlayers bearing brachiopods, ostracodes, and conodonts. Its brachiopod assemblage differs from Givetian (Staryi Oskol) counterparts because of abundant *Uchtospirifer* species. The distribution range of the latter is subdivided into the lower *Uchtospirifer nalivkini* and upper *Uchtospirifer timanicus* local zones. The randomly occurring conodonts of archaic aspect are represented by three taxa: *Polygnathus linguiformis* morphotype *epsilon* Ziegl. et Klap., *P. pseudofoliatus* Witt., and *P. xylus xylus* Stauff. Their position in the section and correlation with concurrent faunas from eastern localities, where conodont assemblages are more diverse, suggest that the Arkhangel-Pasha and Timan stratigraphic intervals in the Moscow basin are conditionally compatible with the *hermanni–cristatus, disparilis*, and *falsiovalis* zones of the standard conodont scale (data of Ovnatanova and Kononova). The spore assemblage with abundant *Archaeozonotriletes micromanifestus* is characteristic of the lower part of the *Contangisporites optivus–Spelaeotriletes krestovnikovii* palynozone. The lower Frasnian (Komi) deposits transgressively overlie Givetian rocks. The Mullino Horizon of the latter is partially or completely eroded in the Voronezh anteclise. In the Moscow syneclise, rocks with the Mullino spore spectrum are unknown. One more phase of basaltic extrusions in the Voronezh anteclise is confined to the commencement of the Arkhangel-Pasha interval. We place the geological boundary (III) between the Givetian and Frasnian stages.

The next *middle Frasnian stage* of sedimentation corresponds to the Russian Superhorizon. It includes sedimentary rhythms of the Sargaevo and Semiluki horizons.

The Sargaevo time marks an initial phase of new transgression, which occurred after a partial erosion of the upper Timan beds and a short break in sedimentation. The transgression was the widest in the Devonian history of the central Russian platform. We inferred several directions of sea water influx: from the Urals in the east, from the Lithuania–Latvia syneclise in the west, and from the Pripyat depression in the southwest.

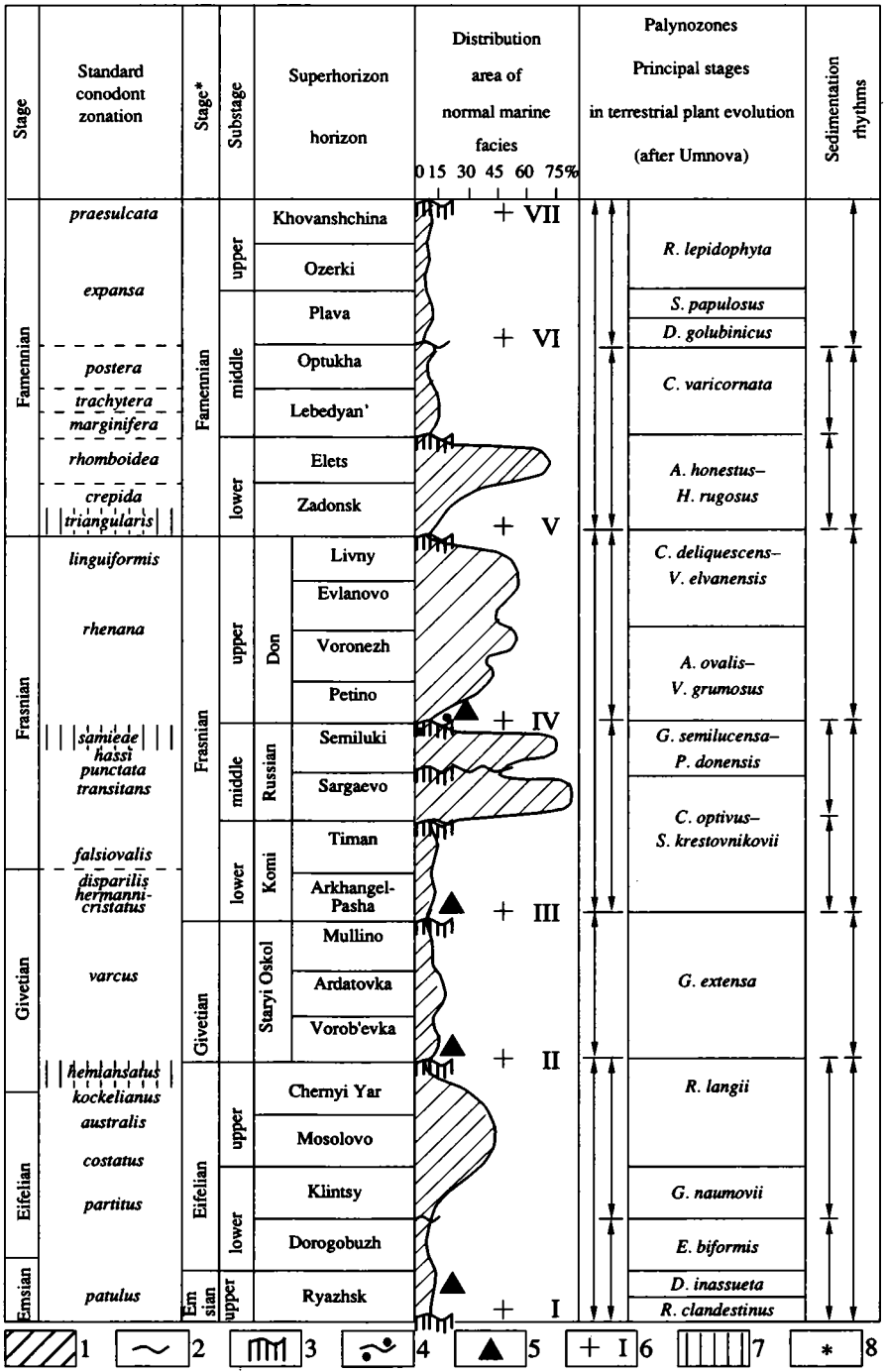


Fig. 5. Secular variations in distribution areas of normal marine facies in the Moscow basin during the Devonian time: (1) normal marine facies; (2) hiatus in sedimentation; (3) the same with erosion; (4) phase of tectonic rearrangement; (5) level of basaltic lavas; (6) main geological boundaries and their number; (7) missing conodont zone; (8) stages accepted in Russia (*Reshenie* ..., 1990).

The Sargaevo Sea represented a paleobasin that accumulated limestone, dolomitic in the west (Fig. 2). Its marine fauna consisted of brachiopods (mostly represented by rhynchonellids), ostracodes, bryozoans, corals, echinoderms, and gastropods. Such forms as *Ladogia meyendorfii* (Vern.), *Hypothyridina calva* Mark., and *Eleutherokomma novosibirica* (Toll.) are the guide fossils of the local brachiopod zone. Another local zone of the *Archaeozonotriletes variabilis* var. *insignis–Acanthotrletes dentatus* spore assemblage corresponds to the upper part of the well-known *Contagisporites optivus–Spelaeotriletes krestovnikovii* Palynozone. According to conodonts recovered from the rhythm in question, the respective deposits were

classified as the *Ancyrodella rotundiloba* Beds (Aristov, 1988) compatible with the *transitans* (lower *asymmetricus*) Zone of the standard conodont scale.

The area of sea water with normal salinity decreased in *the Semiluki time*, when the basin depth was shallower (Fig. 3). This is evident from the clay admixture in carbonates and from the coral–stromatoporoid bioherms abundant in the western part of the basin. Bituminous Domanik-type rocks of the initial Semiluki period are known only in the eastern part of the region. The Semiluki period corresponded to an individual sea transgression, which was responsible for the erosion of upper Sargaevo beds. At the same time, this period represents the regressive phase of the main (Russian) rhythm of sedimentation. Fauna of the Semiluki sea included articulate brachiopods, ostracodes, solitary and colonial corals, bryozoans, gastropods, echinoderms, and bivalves. Brachiopods were flourishing, abundant, and diverse. Numerous representatives of *Cyrtospirifer* and *Stenometoporhynchus* genera made them distinct from the Sargaevo brachiopod fauna, and provided grounds for distinguishing the *Cyrtospirifer rudkinensis–Stenometoporhynchus rudkini* Zone in the lower Semiluki Subhorizon and *Stenometoporhynchus pavlovi–Cyrtospirifer disjunctus* Zone above it. Spores from the interval in question are typical of the *Geminospora semilucensa–Perotriletes donensis* (*Archaeozonotriletes semilucensis–Hymenozonotriletes donensis*) palynozone. The rhythm under consideration is also known as the *Polygnathus timanicus* Beds (Aristov, 1988) correlated with the standard *punctata* and lower *hassi* (middle and upper *asymmetricus*) zones of the conodont scale.

The late Frasnian stage of sedimentation corresponds to the Don Superhorizon comprising the Petino, Voronezh, Evlanovo, and Livny horizons. Sea transgression of the Petino time commenced after a gap in sedimentation. The gap was considerable in the Voronezh anteclise, where Petino–Voronezh beds overlie either different older strata or the crystalline basement. Our analysis of rock facies with variable thickness shows that before the Petino time a stage of tectonic rearrangement modified the past sea into a semiclosed basin that existed, gradually decreasing in size, until the terminal Devonian time. This event also activated the faults framing the Voronezh anteclise on the east, and provoked eruptions of basaltic magma. We consider the natural geological boundary (IV) between the middle and upper Frasnian substages to mark a very important turning point in the Devonian history of the central Russian platform.

During the upper Frasnian period, marine facies of normal salinity were considerably reduced in area as compared to their distribution range in the Semiluki time (Fig. 4). The basin open toward the east was supplied with terrigenous material from the north (Baltic Shield), west (Belarussian anteclise), and south (Voronezh massif). The eastern part of the basin with normal (or almost normal) salinity accumulated the upper Frasnian clay and carbonate beds displaying rhythmical alternation. The coral–bryozoan, coral–stromatoporoid, organodetrital, and algal limestones (25–30 m thick) of the Livny Horizon were deposited in the northern part of the anteclise and in the southeastern part of the syneclise. The terrigenous sedimentation in the northwestern area of the basin behind the Toropets–Tver–Kostroma line produced variegated deposits. A saline lagoon in the western part of the syneclise (near Smolensk and Vyaz'ma) was the accumulation area of dolomites with gypsum interbeds. Terrigenous–carbonate normal marine to shallow-sea deposits of the Voronezh, Evlanovo, and Livny horizons along with littoral sediments of the Petino Horizon accumulated in the south, on slopes of the Voronezh anteclise. Fluctuations of the late Frasnian sea level were pulsatively increasing, as is evident from the Petino, lower and upper Voronezh, and Evlanovo–Livny rhythms. Regressive phases in these rhythms characteristic of the entire Moscow basin are not manifested everywhere.

The upper Frasnian marine facies enclose abundant brachiopods, ostracodes, bivalves, gastropods, corals, and algae. The brachiopod assemblages are rich in species of the *Theodossia* and *Adolfia* genera and are thus distinct from their early and middle Frasnian assemblages. The distinguished sequence of local brachiopod zones is as follows: *Nervostrophia latissima–Adolfia siratschoica* (Petino Horizon), *Theodossia uchtensis–Adolfia krestovnikovi* (lower Voronezh Subhorizon), *Th. tanaica* (upper Voronezh Subhorizon), *Th. evlanensis–Cyrtospirifer* (*Tenticospirifer*) *markovskii* (Evlanovo Horizon), and *Th. livnensis–C.* (*T.*) *tribulatus* (Livny Horizon). Spores occur in all lithologic facies and correspond to the *Archaeoperisaccus ovalis–Verrucosisporites grumosus* (Petino and Voronezh horizons) and *Cristatisporites deliquescens–Verrucosisporites evlanensis* (Evlanovo and Livny horizons) palynozones. The peak abundance of *Archaeoperisaccus* forms is confined to the Petino beds. Marine facies of two former horizons yielded conodonts distinct in species composition from the Semiluki conodont fauna. One species from this interval is *Palmatolepis semichatovae* Ovn. widespread in the Russian platform and characteristic of the standard *rhenana* (*gigas*) Zone. It is inferred that deposits of the upper *hassi* and *jamieae* zones are missing in the Moscow basin (data of Ovnatanova and Kononova). Aristov (1988) identified the Evlanovo and Livny deposits as *Polygnathus brevis* and *P. australis* beds respectively, and correlated them with the standard *rhenana* and *linguiformis* (*gigas*) zones, the latter compatible with the Livny Horizon.

The early Famennian stage of sedimentation is recorded in the Zadonsk and Elets horizons. The Zadonsk transgression in the Moscow basin was after a break in sedimentation. This is evident from the following data: deposits analogous to Domanovichi and Kuzmichi beds of Belarus are missing here; brachiopod, ostracode, and spore assemblages considerably

changed in composition; and the *triangularis* Zone of the conodont scale seems also to be missing (conclusion of Ovnatanova and Kononova). Accordingly, we place the natural geological boundary (V) between the Frasnian and Famennian stages.

The Zadonsk–Elets transgression prograded from the east (Urals) and southeast (Caspian depression). It was the widest ingression of sea water after the Semiluki transgression. Almost throughout the basin, the water salinity was normal or close to normal, and the sea was populated by abundant brachiopods, ostracodes, bivalves, and other faunas. In the main part of the basin, the Zadonsk strata consist of clay–carbonate sediments, which are rich in sandy fraction in marginal zones, especially in the northwestern area. During the Elets time, the Moscow basin predominantly accumulated carbonates. The lower Famennian interval corresponds to a single rhythm of sedimentation, whose basal part is represented by the Zadonsk Horizon, whereas the Elets Horizon marks the transgression maximum. The regressive phase is poorly manifested, or absent. A distinct change in composition of brachiopod, ostracode, conodont, and spore assemblages is confined to the lower–middle Famennian boundary, and deposits equivalent to the Petrikovo beds of Belarus are missing at this level, which suggests the next hiatus in sedimentation.

Brachiopods from the Zadonsk–Elets interval are abundant, but not very diverse. Atrypids, pentamerids, and *Theodossia* genus disappeared from their assembalges, which included the new *Cyrtospirifer* and abundant *Ripidiorhynchus zadonicus* (Nal.) species and thus were distinct from the late Frasnian brachiopod assemblages. The distinguished sequence of local brachiopod zones is identified on the basis of the following guide species: *Cyrtospirifer zadonicus–C. asiaticus–Ripidiorhynchus zadonicus* (Zadonsk Horizon) and *C. Gridi–R. Gridicus* (Elets Horizon). According to Umnova, spores from the lower Famennian interval correspond to the *Archaeozonotriletes honestus–Nymenozonotriletes rugosus* Palynozone. Aristov (1988), who studied conodonts from the Zadonsk Horizon, identified the latter as the *Icriodus iowaensis* Beds correlative with the standard *crepida* Zone. As noted, the *triangularis* Zone is likely missing in the central Russian platform. The Elets Horizon, otherwise known as *Palmatolepis subperlobata–P. wolskae* Beds, was correlated with the standard *rhomboidea* Zone.

During the terminal *middle and late Famennian stages* of Devonian sedimentation, the Moscow basin represented a semiclosed saline lagoon with impoverished fauna. The lagoon accumulated sedimentary dolomites intercalated with gypsum interbeds. The rocks yielded spores of the *Cornispora varicornata* (Lebedyan' and Optukha horizons), *Discernisporites golubinicus–Spelaeotriletes papulosus* (Plava Horizon), and *Retispora lepidophyta* (Ozerki and Khovanshchina horizons) zones. The peak ingression of sea water with normal salinity was at the late Plava (Kudeyarovo) time. The last period corresponds to the local *Sinotectirostrum otrada–Cyrtospirifer kapsedensis* brachiopod zone. The middle–upper Famennian marine facies of the Voronezh anteclise bearing conodonts are divided into *Pelekysgnathus curtus* (Lebedyan), *P. australis* (Optukha), *Polygnathus irregularis–Neoicriodus ? salebrosus–Antognathus volnovachensis* (Plava), and *Pelekysgnathus peejayi* (Ozerki and Khovanshchina) beds (Aristov, 1988). Their section comprises the sequence of standard conodont zones from *marginifera* to *praesulcata* inclusive (Fig. 5). The natural geological boundary (VI) between the Optukha and Plava horizons is of a distinct lithologic type. The lower Plava (Turgenevo) beds consisting of massive clayey to sandy dolomites transgressively overlie the upper Optukha (Kiselevo–Nikol'skoe) strata of laminar pelitomorphic dolomites with gypsum interbeds. The basal Turgenevo beds of the Voronezh anteclise are composed of sandstone. The indicated boundary corresponds to the first occurrence level of Carboniferous brachiopods and ostracodes in association with their Devonian forms. It is also the upper limit for the *Cornispora* species replaced upsection by *Retispora lepidophyta*.

The Devonian–Carboniferous boundary in the Moscow basin (no. VII in our terminology) is marked by a hiatus in sedimentation. The Zigan Horizon, *R. lepidophyta–Vallatisporites pusillites* palynozone, and several ostracode zones are missing here.

Distinct turning points in the history of Devonian sedimentation in the Moscow basin correspond to boundaries between principal stratigraphic units and large sedimentary rhythms. They are marked by significant changes in fossil assemblages, and coincide with hiatuses in sedimentation and certain levels of volcanic eruptions. By and large we distinguished the Lower–Middle Devonian (I), Eifelian–Givetian (II), Givetian–Frasnian (III), middle–upper Frasnian (IV), Frasnian–Famennian (V), middle Famennian or Optukha–Plava (VI), and Devonian–Carboniferous (VII) boundaries of this rank.

The main geological events that were detected in the middle–upper Frasnian and Famennian intervals of sedimentation history in the Moscow basin (Fig. 6) can be correlated with some well-known eustatic events of the Devonian time (Johnson *et al.*, 1985; Johnson and Sandberg, 1988). However, there is certain disagreement between the curves under comparison, which is especially evident in the Givetian interval. The reference curve depicts the gradual sea level rise after the Eifelian Age, whereas in the Russian platform, the level lowered considerably during the Givetian time. Apparently, the inferred Devonian fluctuations of sea level in the Russian platform should be refined by using biofacial and sedimentiological analysis of past environ-

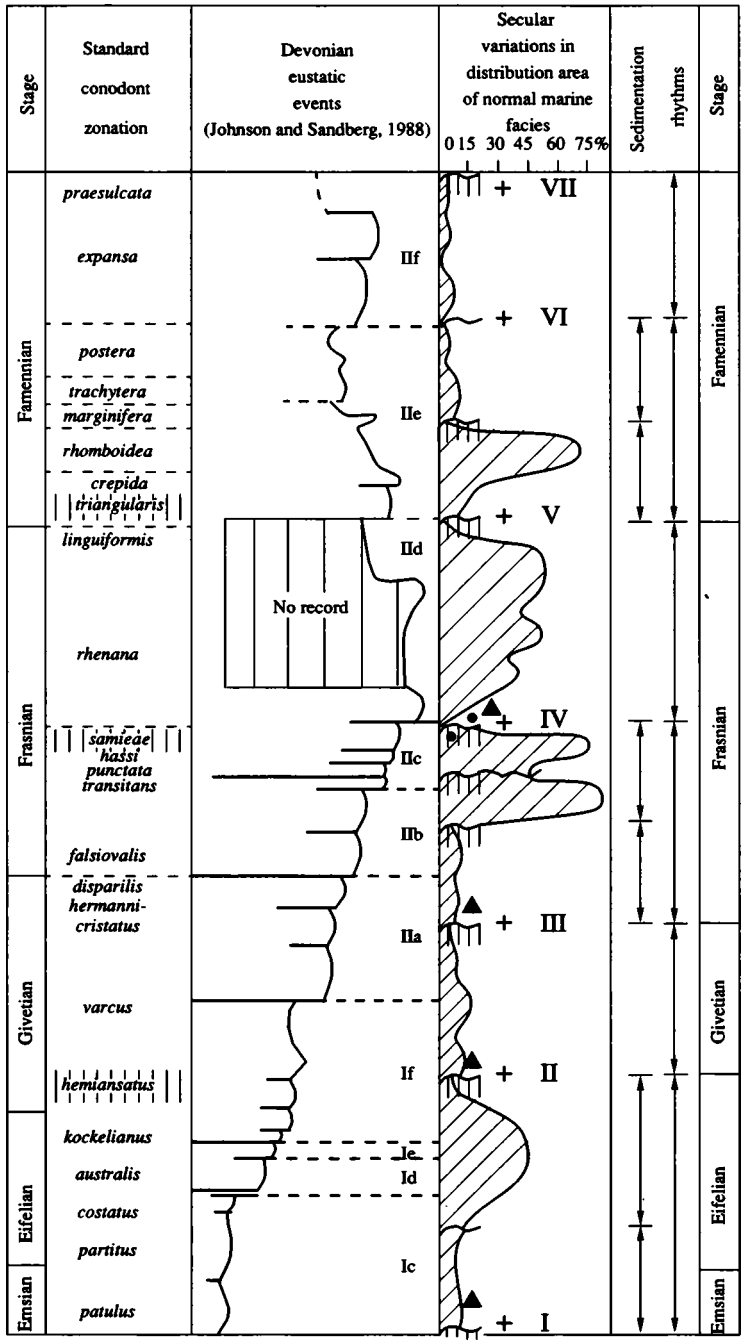


Fig. 6. Secular variations in distribution areas of normal marine facies in the Moscow basin during the Devonian time correlated with eustatic events (Johnson and Sandberg, 1988); symbols as in Fig. 5.

ments. In our opinion, the palynological correlation of different sedimentary facies may contribute much to the solution of the problem.

Reviewer A.S. Alekseev

REFERENCES

Aristov, V.A., *Devonskie konodonty Tsentral'nogo Devonskogo polya (Russkaya platforma)* (Devonian Conodonts of the Central Devonian Field, Russian Platform), Moscow: Nauka, 1988.

Johnson, J.G., Klapper, G., and Sandberg, C.A., Devonian Eustatic Fluctuations in Euramerica, *Bull. Geol. Soc. Am.*, 1985, vol. 96, pp. 567–587.

Johnson, J.G. and Sandberg, C.A., Devonian Eustatic Events in the Western United States and their Biostratigraphic Responses, *Devonian of the World,* vol. 3, McMillan, N.G.,

Embry, A.F., and Glass, D.A., Eds., New York: Wiley, 1988, pp. 171–193.

Rodionova, G.D., Umnova, V.T., Kononova, L.I., *et al.*, *Devon Voronezhskoi anteklizy i Moskovskoi sineklizy* (The Devonian in the Voronezh Anteclise and Moscow Syneclise), Moscow: Rosgeolfond, 1995.

Rzhonsnitskaya, M.A. and Kulikova, V.F., The Devonian in the Russian Platform, in *Stratigrafiya i paleontologiya devona, karbona i permi Russkoi platformy* (Devonian, Carboniferous, and Permian Stratigraphy and Paleontology of the Russian Platform), Leningrad: Vses. Geol. Inst., 1991, pp. 11–21.

Tikhomirov, S.V., *Etapy osadkonakopleniya devona Russkoi platformy* (Devonian Stages of Sedimentation in the Russian Platform), Moscow: Nedra, 1967.

Umnova, V.T. and Rodionova, G.D., Devonian Stratigraphy and Palynology of the Russian Platform, in *Stratigrafiya i paleontologiya devona, karbona i permi Russkoi platformy* (Devonian, Carboniferous, and Permian Stratigraphy and Paleontology of the Russian Platform), Leningrad: Vses. Geol. Inst., 1991, pp. 47–53.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 126–130. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 29–34.
Original Russian Text Copyright © 1997 by Ganelin, Goman'kov, Grunt, Durante, Lazarev, Morozova, Osipova.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

On the Revised Stratigraphic Scale for the Permian System Adopted at the Second Guadalupian Symposium, Alpine, Texas, USA, April 1996

V. G. Ganelin*, A. V. Goman'kov*, T. A. Grunt, M. V. Durante*, S. S. Lazarev**, I. P. Morozova**, and A. I. Osipova****

** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*
*** Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117321 Russia*
Received May 29, 1996

Abstract—The proposals for the principal subdivision of the Permian System, which were approved by the International Subcommission on Permian Stratigraphy (SCPS) at the II Guadalupian Symposium in April 1996, Texas, United States, are critically analyzed. It was proposed to change the traditional two-fold subdivision of the Permian System to three series and to establish stratotypes of the series (subseries) not in a single stratotype region such as the Cisurals, where they have been located for the last 150 years, but in different continents. The type sections of the lower (Cisuralian) series only were retained in the Cisurals, whereas those of the middle (Guadalupian) and upper (Lopingian) subseries (series) were chosen in Texas, USA and southern China, respectively. However, the boundaries of the Guadalupian and Lopingian subseries (series) cannot be recognized with confidence outside the equatorial zone. This is more true for the boundaries between their component stages. As for fossil marine invertebrates (conodonts, fusulinids, and ammonoids), which provide the subdivision and correlation of the Guadalupian and Lopingian subseries (series), single condonts and rare ammonoids were represented by different genera, but no fusulinids were found in the Boreal and Notal climatic zones. The scale proposed by the Subcommission does not show the position of an important paleomagnetic level—the boundary between the Kiaman and Illawarra hyperzones. This boundary was not recorded in the equatorial zone, but it is reliably determined in the stratotype section of the Tatarian Stage in the Cisurals, where it coincides with the substage boundary. Thus, the proposed scale cannot be applied to most of the Permian basins and is in essence provincial. The decision to approve the subdivisions of this scale as international standards seems to be premature. It is suggested to set up some working groups of the International Subcommission on Permian Stratigraphy to solve the problems of correlation and standard subdivision of the Permian System.

Key words: *Permian, stratigraphy, correlation, paleobiogeography.*

In recent years (1992–1996), the International Permian stage scale has been the subject of radical revision. A formal reason for abandoning the traditional stages is that the Kungurian, Ufimian, and Tatarian stages are not sufficiently (in the opinion of some specialists dealing with Permian stratigraphy of North America and Southern Eurasia) characterized by fossils.

From the time of Murchison (1841), the Cisurals has been considered to be a single stratotype region both for the Permian System as a whole and for its components (two series and seven stages). According to the proposals of the International Subcommission on Permain Stratigraphy (SCPS) of the International Commission on Stratigraphy of the International Union of Geological Sciences (IUGS), the Permian System is subdivided into three units, whose stratotypes are located in three different continents (table).[1]

[1] After this paper was submitted for publication, the SCPS published another variant of the standard Permian scale (Jin Yugan, 1996; Spinosa, 1996) and simultaneously put it to a postal ballot. Thus, this variant has been formally approved without being discussed in press.

A stratotype section is retained in the Cisurals for the lower (Cisuralian) series only, whereas the stratotype sections of the lower (Guadalupian) and upper (Lopingian) subseries of the upper series are proposed to be selected in Texas, United States, and southern China, respectively. However, the Uralian area and Russian platform are the stratotype region of the Permian System as a whole, and the Kungurian, Ufimian, and Kazanian stages were the first to be distinguished in the Permian deposits. Until the beginning of our century, all Lower Permian deposits, except for the Kungurian stage, were referred to the Permo-Carboniferous.

It is obvious that the official approval of the boundaries of the Guadalupian and Lopingian subseries will result in the automatic adoption of their component stages recognized in the United States and China. This means the abandoning of the Cisurals as the classical stratotype region for the Permian System, which was established over 150 years ago.

Any proposals to improve the Permian scale should be considered in the following aspects:

Revision of the Permian stratigraphic scale

Ruzhentsev *et al.*, 1965		Glenister *et al.*, 1992		Glenister *et al.*, 1993		Jin Yugan *et al.*, 1994		Glenister *et al.*, 1994		II Guadalupian Symposium, 1996	
Triassic		Triassic		Triassic		Triassic		Triassic		Triassic (Greisbachian)	
Upper Permian	Dzhulfian	Upper Permian (Lopingian Series)		Upper Permian (Lopingian Series)		Middle Permian	Changsingian	Middle Permian	Changsingian	Middle Permian	Changsingian
							Lopingian Subseries		Lopingian Subseries		Lopingian Subseries
							Dzhulfian (Wuchapingian)		Wuchapingian		Wuchapingian
											Laibinian
	Capitanian	Middle Permian	Capitanian	Middle Permian	Capitanian		Capitanian		Capitanian		Capitanian
					Wordian		Guadalupian Series		Guadalupian Series		Guadalupian Series
			Guadalupian Series		Guadalupian Series		Wordian		Wordian		Wordian
	Wordian (the *Waagenoceras* zone)		Wordian		Roadian		Roadian		Roadian		Roadian
			Roadian		Cathedralian	Lower Permian	Kubergandian	Lower Permian	Cathedralian	Lower Permian	Kungurian
Lower Permian	Artinskian (including Kungurian)	Lower Permian	Artinskian	Lower Permian	Artinskian		Chihsian Subseries		Chihsian Subseries		Cisuralian Subseries
							Bolorian		Hessian		
			Uralian Series		Uralian Series		Artinskian		Artinskian		Artinskian
	Sakmarian		Sakmarian		Sakmarian		Uralian Subseries		Cisuralian Subseries		Sakmarian
							Sakmarian		Sakmarian		
	Asselian		Asselian		Asselian		Asselian		Asselian		Asselian
Carboniferous		Carboniferous		Carboniferous		Carboniferous (Gzhelian)		Carboniferous (Gzhelian)		Carboniferous (Gzhelian)	

(1) How reliable are the interregional correlations of the proposed boundaries, i.e., how contiguous are the regional stratigraphic scales (in this case, the East European scale with the North American scale and the latter with the Tethyan or South Chinese scale) and, correspondingly, is a new scale more valid, better substantiated, and more informative than the traditional East European scale?

(2) How sufficient are the paleontologic characteristics of the relevant stratigraphic subdivisions?

(3) To what extent is a new scale substantiated by the Permian paleogeographic and biogeographic data?

The table presents several versions of the revised standard Permian scale that have been compiled since 1992. Even a cursory examination shows that the lower boundary of the Guadalupian Subseries (Series) was the only subject of revision in the first four versions. Every suggestion was subjected to criticism (*Permophiles*, 1993–1996) and then a new one was put forward. The very diverse scales, which appeared in a short time span, bear witness to the extreme difficulty of making the lower boundary of the Guadalupian Subseries (Series) coincident with the upper boundary of the Cisuralian Series. It also remains unclear whether the upper boundary of the Guadalupian Subseries (Series) can be correlated with the lower boundary of the Lopingian Subseries. As a result, the International Symposium "Evolution of Permian Marine Biota" (*Mezhdunarodnyi...*, 1995; *Putevoditel'...*, 1995; Chuvashov *et al.*, 1995), which was organized by the Paleontological Institute of the Russian Academy of Sciences (Moscow), the Institute of Geology of the Komi Scientific Center of the Uralian Division of the Russian Academy of Sciences (Syktyvkar), and the Institute of Geology and Geochemistry of the Uralian Division of the Russian Academy of Sciences (Yekaterinburg), arrived at an agreement to retain the traditional volume of the Lower Permian Series.

The version adopted at the II Guadalupian Symposium first suggested the correspondance between the Roadian Stage of the North American scale and the Ufimian Stage of the East European scale. Until the mid-1980s, the Roadian fauna of ammonoids (Furnish, 1973; Ruzhentsev, 1976), conodonts (Wardlaw and Collinson, 1984), and brachiopods (Cooper and Grant, 1972–1977) was commonly considered to be of the Early Permian age. This widespread opinion was reflected in the "Global Stratigraphic Chart" (Cowie and Bassett, 1989).

Most Russian researchers point out that the Roadian stage does not correspond to the Ufimian Stage in range. Some specialists correlate the Roadian Stage to the lower (Solikamsk) horizon of the Ufimian Stage (Chuvashov, 1984), and the others, to its upper (Sheshma) horizon. The latter opinion is now becoming prevalent. Thus, it must be admitted that the recognition of the Ufimian Stage (established by A.V. Nechaev in 1915), which has a certain position in the scale, two component horizons, and sufficient fossil content (both in marine and continental facies), validated the scale and facilitates refined correlations, including interregional ones. This allows us, despite the common opinion of the low potential of the Ufimian Stage for correlation, to specify the stratigraphic position of the Roadian Stage. However, this cannot justify substituting the Ufimian Stage for the Roadian Stage; on the contrary, this proves the necessity to retain the Ufimian Stage in the standard scale. In addition, the statements that the Roadian Stage belongs to the Upper Permian and corresponds to the whole Ufimian Stage or its part are still made in a declarative and predominantly oral form. There are no serious publications dealing with this problem. Therefore, it seems necessary to set up an international working group for the comprehensive study of the boundary between the lower and upper Permian series in the Russian platform and its correlation with the coeval levels in North America, Tethyan area, Kolyma-Omolon massif, Verkhoyansk region, and Australia, as was suggested at the international symposium on evolution of Permian marine biota (Chuvashov *et al.*, 1995). Special attention should be given to the northern Russian platform, which exhibits marine deposits of this age interval. Particularly, the Permian reference section in the Kolyma-Omolon massif (the Vodopandyi Creek section) displays a continuous succession of marine deposits ranging from the Artinskian Stage to the Tatarian Stage inclusive (*Opornyi...*, 1990).

Up to the present, the lower boundary of the Lopingian Subseries has virtually not been discussed (see table), although it presents a complicated problem. In many scales the lower boundary of the Dzhulfian Stage is shown coincident with the upper boundary of the Capitanian Stage, but this is evidently not the case. Until recently, the coincidence of the lower boundaries of the Dzhulfian and Wuchapingian stages has been tacitly accepted. Now it has become obvious that the lower boundary of the Wuchapingian Stage lies much lower than that of the Dzhulfian Stage. This boundary cannot even be a subject of discussion because the only relevant publication (Kozur, 1995) deals with a new poorly substantiated Laibinian Stage, which is proposed to be placed between the Dzhulfian and Capitanian stages. It is impossible even approximately to define a position of the lower Lopingian boundary in the boreal sections.

The proposed subdivisions are paleontologically substantiated by three fossil groups: ammonoids, fusulinids, and conodonts. This choice is appropriate for the Lower Permian. However, no fusulinids, sporadic conodonts, and rare ammonoids are known to occur in the Upper Permian sections of the Boreal and Notal areas. Therefore, the proposed variant characterizes the tropical sections without making allowance for the nontropical localities. Particularly puzzling is the fact that all zonal boundaries defined by these three fossil groups appear to be coincident throughout the Permian sequence. The chosen approach absolutely

ignores the interchangeability principle, which was declared by the International Commission on Stratigraphy. No fossil group that could facilitate the correlation with nontropical basins was used.

A section of marine Guadalupian deposits, which was suggested as the stratotype for the Guadalupian Subseries (Series), is indeed well exposed. This section throughout a fossil atoll surrounded by distal and proximal reef facies is a unique natural object of limited extent. It shows very complicated relationships between various formations and their constituents. There are numerous interformational and intraformational hiatuses. Paleogeographically, the semi-isolated Guadalupian basin belonged to the larger Delaware basin, which, in its turn, was part of the extensive North American equatorial basin (Midcontinent). Biogeographic connections of the latter with the Eurasian basins were extremely difficult. In contrast, the water areas of the Russian platform, which occupied the central position in the system of the Euro-Asiatic basins, had intensive migrational connections with the Canadian Arctic, northeastern Asia, and Tethyan area. Biogeographic connections between these water areas and peri-Gondwana have been recently outlined. In addition, in the Late Permian, the Cisurals was located at the temperate latitudes of the Boreal area and was bordered in the south by the equatorial zone. This position increases the potential of the stratotypes in this area for correlation with both equatorial and boreal sections. It is also significant that the Russian platform sections enable us to correlate the marine and continental deposits because they display the entire spectrum of transitional facies. This gives rise to the hope that a standard stratigraphic scale for marine and continental deposits will finally be elaborated. Spore-pollen assemblages that spread virtually in all type of facies can be used for this purpose.

It is of significance that the boundary between the lower and upper (middle) series of the Permian System is far from being defined by using the conodont zonation of individual sections of the equatorial climatic zone. As established by Nechaev in the Russian platform sections, the boundary between the Permian series is the most significant level indicating ecological and evolutionary changes in marine and terrestrial biotas. The boundary between the Guadalupian and Lopingian subseries (series) is a level of much lower rank.

While discussing the correlation potential of the Uralian scale, we should remember that the boundary between the Kiaman and Illawarra paleomagnetic hyperzones was comprehensively studied only in the Tatarian sections, which can be considered as reference sections for this boundary. The latter has been accurately determined neither in the Tethys nor in the North American basins. From this standpoint, the adoption of the new scale for the Upper Permian Series seems to be at least premature.

More caution is needed in the radical revision of the scale for the Upper Permian Series so that the existing difficulties will not be followed by new, more significant ones.

Obviously, the problems of Permian stratigraphy stem from the complicated paleogeographic settings of the Permian Period and, especially, its terminal phases, rather than from the uncompleteness of the stratotypes of some stages.

In this situation, it would be naive to admit that the standard scale for the Permian System can be improved by substituting one stratotype section for another. This substitution is an extreme measure, which should be taken when all other possibilities appear to be exhausted, and after a detailed analysis of all alternatives, careful preliminary work, and a final selection of the best candidate supported by the majority of specialists.

Meanwhile, the proposed new version of the Permian subdivisions is obviously a hasty decision. It does not appear to be applicable beyond the limits of the equatorial zone. Vast areas of the Permian basins of Northern Eurasia (*Stratigraficheskie...*, 1994; *Opornyi...*, 1990) and Gondwana (Archbold and Dickins, 1993), recent studies of which have provided great advances in Permian biostratigraphy, were not considered by this version at all. The SCPS also ignored a formal proposal of Taraz (1996) to select a stratotype of the Middle Permian Series among the sections of Central Iran.

Artificially subdivided into three units, whose stratotypes are in three different continents (or three different basins), the standard Permian scale becomes desintegrated. It appears to be useless for global correlations because its subdivisions cannot be recognized outside the equatorial zone.

The scale proposed by the Subcommission on Permian Stratigraphy may be officially accepted as an auxiliary one for equatorial correlations (just as, for example, the independent parallel scale for the southern regions of the former USSR; Leven, 1980). However, the approval of these subdivisions as international standards at present seems to us premature. It can considerably hamper the search for a more acceptable variant.

The idea to attach proper names to proposed subseries (series) is completely intolerable because this procedure will inevitably result in the automatic acceptance of relevant stages.

So far as is known, the subcommission on Triassic Stratigraphy (which is responsible for the selection of the lower boundary of the Triassic System) has not yet made a decision on this point. Therefore, it is important in this complicated situation not to hasten with the official decision on fixing proper geographic names of subseries (series).

The expediency of retaining the traditional stages in the Standard Permian stratigraphic scale is based, along with the above reasons, on the necessity of achieving maximal stability and universalism in nomenclature.

This can be achieved immutably following the priority principle (relative to names rather than the entitative aspect of relevant stratigraphic units).

This means that the changes of the traditional names of the Permian stages for those defined in the American and Chinese sections (which is inevitable after the subseries names are approved) not only destabilize a general situation concerning the Permian scale but also violate the priority principles, which are generally accepted as nomenclatural and ethical standards in science.

It is obvious that the Russian and Chinese sections are the most representative and promising for the elaboration of the standard scale. The North American sections, which are biogeographically isolated and show unsufficiently characterized lower and upper parts, are not so representative.

Therefore, the pressing efforts of the North American specialists to incorporate the North American stratigraphic units into the standard scale look very hasty. They stem from the idea of national prestige rather than the necessity of improving the existing scale.

We appreciate the fruitful activity of the Subcommission on Permian Stratigraphy, which defined the problems to be studied by working groups in the coming years. However, more caution is needed in taking official decisions, especially if no agreement has been reached by specialists (a formal postal ballot cannot be considered as an appropriate means). This is particularly true when the acceptance of a new stratigraphic scale leads to the radical change of the traditional (and priority) notions.

Reviewer A.S. Alekseev

REFERENCES

Archbold, N.W. and Dickins, J.M., *A Standard for the Permian System in Australia,* Adelaide: Bureau Min. Res. Geol. Geophys., 1989.

Chuvashov, B., Bogoslovskaya, M., Grunt, T., *et al.*, International Symposium "Evolution of Permian Marine Biota," *Permophiles,* 1995, no. 27, pp. 27–30.

Chuvashov, B.I., *Artinskii yarus nizhnei permi: problemy raschleneniya i korrelyatsii* (The Artinskian Stage of the Lower Permian: Problems of Subdivision and Correlation), Sverdlovsk: Inst. Geol. Geochem., Ural. Otd., Akad. Nauk SSSR, 1984.

Cooper, G.A. and Grant, R.E., *Permian Brachiopods of West Texas.* 6 vols., Washington: Smithsonian Contrib. Paleobiol., 1972–1977.

Cowie, J.W. and Bassett, M.G., *Global Stratigraphic Chart with Geochronometric and Magnetostratigraphic Calibration,* Intern. Union Geol. Sci., 1989.

Furnish, W.M., Permian Stage Names in Permian and Triassic System and Their Mutual Boundary, *Mem. Can. Soc. Pet. Geol.,* 1973, no. 21973, pp. 522–548.

Glenister, B.F. and Furnish, W.M., The Permian Ammonoids of Australia, *J. Paleontol.,* 1961, no. 35, pp. 673–736.

Glenister, B.F., A Call to Action, *Permophiles,* 1993, no. 22, pp. 2-5.

Glenister, B.F., Boud, D.W., Furnish, W.M., *et al.*, The Guadalupian: Proposed International Standard for the Middle Permian Series, *Int. Geol. Rev.,* 1992, vol. 34, no. 9, pp. 657–688.

Jin Yugan, A Global Chronostratigraphic Scheme for the Permian System, *Permophiles,* 1996, no. 28, pp. 4–10.

Jin Yugan, Glenister, B.F., Kotlyar, G.V., and Sheng Jinzhang, An Operational Scheme of Permian Chronostratigraphy, *Palaeoword,* 1994a, vol. 4, pp. 1–13.

Jin Yugan, Sheng Jinzhang, Glenister, B.F., *et al.*, Revised Operation Scheme of Permian Chronostratigraphy, *Permophiles,* 1994b, no. 25, pp. 12–15.

Kozur, H. and Mostler, H., Guadalupian (Middle Permian) Conodonts of Sponge-Bearing Limestones from the Margins of the Delaware Basin, West Texas, *Geol. Croatia,* 1995, vol. 48, no. 2, pp. 107–128.

Leven, E.Ya., *Ob'yasnitel'naya zapiska k stratigraficheskoi shkale permskikh otlozhenii oblasti Tetis* (Explanatory Note for the Permian Stratigraphic Scale of the Tethyan Area), Leningrad: Vses. Geol. Inst., 1980.

Mezhdunarodnyi simpozium "Problemy evolyutsii permskoi morskoi bioty" s ekskursiei na permskie otlozheniya r. Kozhim, respublika Komi, Tezisy dokladov (Int. Symp. "Problems of Evolution of the Permian Marine Biota" with Excursion to the Permian Deposits at the Kozhim River, Komi Republik, Abstracts), Moscow: Paleontol. Inst., Ross. Akad. Nauk., 1995.

Murchison, R.I., Geological Observations in Russia, *Geol. Zh.,* 1841, vol. 4, nos. 11–12, pp. 160–170.

Nechaev, A.V., The Kazanian and Ufimian Stages of the Permian System, *Geol. Vestn.*, 1915, vol. 1, no. 1, pp. 4–6.

Opornyi razrez permi Omolonskogo massiva (The Permian Reference Section in the Omolon Massif), Leningrad: Nauka, 1990.

Permophiles, 1993–1996, nos. 23–28.

Putevoditel' ekskursii na permskie otlozheniya r. Kozhim (Guide-Book of the Excursion to the Permian Deposits at the Kozhim River), Moscow: Paleontol. Inst., Ross. Akad. Nauk, 1995.

Ruzhentsev, V.E., Late Permian Ammonoids from the Far East, *Paleontol. Zh.,* 1976, no. 2, pp. 36–50.

Ruzhentsev, V.E., Sarycheva, T.G., and Shevyrev, A.A., Biostratigraphic Inferences, in *Razvitie i smena morskikh organizmov na rubezhe paleozoya i mesozoya* (Evolution of Marine Organisms and their Changes at the Paleozoic–Mesozoic Boundary), Moscow: Nauka, 1965, pp. 93–116.

Second Int. Guadalupian Symp.: Abstracts and Proc., Wardlaw, B.R. and Rohr, D.M., Eds., Alpine: Sul Ross State Univ., 1996.

Spinosa, C., Subcommission on Permian Stratigraphy: Report on the Meeting in Alpine, Texas, *Permophiles*, 1996, no. 28, pp. 1–4.

Stratigraficheskie skhemy Urala: dokembrii, paleozoi (Stratigraphic Schemes of the Urals: Precambrian and Paleozoic), Antsygin, N.Ya, Popov, B.A., and Chuvashov, B.I., Eds., Yekaterinburg: Inst. Geol. Geochem., Ural. Otd., Ross. Akad. Nauk, 1994, 151 Sheets.

Taraz, H., Middle Permian Stratotype, *Permophiles*, 1996, no. 28, p. 10.

Wardlaw, B.R. and Collinson, J.W., Conodont Paleoecology of the Permian Phosphoria Formation and Related Rocks of Wyoming and Adjacent Areas, in *Conodont Biofacies and Provincialism, Spec. Paper Geol. Soc. Am.,* 1984, no. 196, pp. 263–281.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 131–146. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 35–50.
Original Russian Text Copyright © 1997 by Kotlyar.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Correlative Reference Levels of the Permian

G. V. Kotlyar

All-Russia Research Institute of Geology (VSEGEI), Srednyi pr. 74, St. Petersburg, 199026 Russia

Received April 17, 1995; in final form, July 27, 1995

Abstract—The analysis of Permian biotic and abiotic events has revealed a series of contrasting global biostratigraphic levels, to which significant changes in faunal assemblages are confined. The most important among them—the "Kungurian," Kubergandian (Roadian) and Djulfian stages—are related to transgressions, the Kungurian being also associated with a large-scale paleogeographic reorganization. The global character of these transgressions and related biotic changes are caused most likely by eustatic sea level fluctuations. The most significant changes in the Permian biota, which showed up differently in basins of the Boreal and Tethyan realms, occurred in the early "Kungurian" time. The Kubergandian (Roadian) Stage is associated with a wide geographic distribution of the Roadian ammonoid assemblage, which includes the Ceratitida order, and the simultaneous appearance of *Mesogondolella nankingensis*. The Djulfian Stage is characterized by the extinction of almost all higher fusulinids, the mass development of aberrant genera, the appearance of araxoceratids, and substantial changes in the evolution of corals, brachiopods and other faunal assemblages. Levels of a lower order are also established. One of them corresponds to the maximum development of the mid-Permian transgression (the *Neoschwagerina craticulifera–Afghanella schencki* Zone in the Tethys and its analogues in other areas) and marks the appearance of the Wordian ammonoid assemblage. The mid-Midian level coincides in time with the boundary of the Kaiama and Illawarra paleomagnetic hyperzones and is marked by the appearance of the Capitanian zonal genus *Timorites*. The stages revealed here represent reference levels, which allow wide correlations to be made.

Key words: *Permian, correlation, biostratigraphy, scale, stage, scheme, zone, assemblage.*

The need for elaborating the global standard of the Permian System based on marine sections has long been apparent. However, such a scale should be preceeded by a detailed interregional correlation of Permian deposits based on zonal stratigraphy.

Essential differences between the faunas of the Boreal and Tethyan realms required the elaboration of scales of regional stages for each of them.

The scale for the Tethys was approved by the Interdepartmental Stratigraphic Committee (Resolution ..., 1981) and employed successfully over a long period of time. The basis for this scale is the evolutionary line of fusulinids, one of the leading fossil groups of this province, which provides a detailed subdivision of deposits and reliable correlations within the whole province (Table 1).

The scale for the Boreal realm is nearing completion, and the reference section of marine deposits, complete, well-studied, and subdivided in full detail in the Kolyma–Omolon province of northeast Russia, is considered as a candidate for the stratigraphic standard (Kashik *et al.*, 1990). The section comprises 15 local zones substantiated comprehensively and dated on the basis of combined ammonoid, brachiopod, foraminifer and bivalve zonal assemblages. Many of the local zones distinguished by V.G. Ganelin are traced within a considerable part of the Boreal realm (Table 2).

The analysis of the Permian biotic and abiotic events within the Boreal and Tethyan realms revealed a series of reference levels useful for interregional correlation.

A marked biostratigraphic level of the Early Permian in the Boreal realm, marking changes in fossil assemblages, is confined most likely to the earliest "Kungurian." In the eastern part of the realm (the Taimyr–Kolyma, Verkhoynsk–Okhotsk and Yukon basins), the Early Permian is characterized by the "Verkhoyansk," assemblages extremely endemic and closely related to the Carboniferous fauna and comprises some taxa widely developed in the Carboniferous, among which diverse *Jakutoproductus* dominate (the Munugudzhak Horizon and its analogues). A substantial change in fossil assemblages occurred at the boundary between the Munugudzhak and Dzhigdali horizons (Kashik *et al.*, 1990). A peculiar ammonoid assemblage (the Kungurian, in M.F. Bogoslovskaya's opinion), including genera *Neouddenites, Tumaroceras, Epijuresanites,* and *Uraloceras* along with inoceramid-like bivalves of the *Aphanaia* genus, appeared here, whereas representatives of the *Jakutoproductus* genus died out. The brachiopod assemblage is highly similar to the Svalbardian, Talata–Lek-Vorkuta, and Pai-Khoi assemblages. Anidantids of the Urals-Pechora (Svalbardian) affinity, e.g., *Anidanthus aagardi* (Toula), are its dominant forms and associate

Table 1. Correlation of Permian deposits in the Tethys

Tethys, general scale (Leven, 1980; 1993)				Transcaucasia (Kotlyar *et al.*, 1983; 1989)		Central Iran, Abadeh (Iran, Jap. Gr., 1981)			Southeastern Pamir (Leven *et al.*, 1989)		Southwestern Darvaz (Leven *et al.*, 1989)
Permian	Upper	Dorashamian		Dorasham	*Pleuronodoceras*	Hambast Formation	Member 7	*Paratirolites*	Takhtabulak Formation	*Colaniella parva*	
			Paratirolites		*Paratirolites*					*Clarkina subcarinata*	
			Phisonites		*Phisonites*			*Shevyrevites*			
		Djulfian	*Vedioceras ventroplanum*	Djulfa	*Videoceras*		Member 6	*Videoceras*		*Colaniella cylindrica*	Kafirbacha Formation
			Araxoceras latum		*Araxoceras*			*Araxoceras*			
		Midian	*Codonofusiella*	Khachik	*Codonofusiella kwangsiana*	Abadeh	Member 5	*Codonofusiella kwangsiana*		*Reichelina cribroseptata*	
			Lepidolina		*Baisalina pulchra*		Member 4	*Yabeina* *Baisalina pulchra*	Gan	Kutal Member	*Stepanovites inflatus*
			Yabeina							*Mesogondolella postserrata*	Kaftarmol, Shakarsev, Khamtarma
			Neoschwagerina margaritae	Arpa	*Chusenella abichi*	Surmag Formation	3	*Chusenella abichi*		*Yabeina archaica* *N. margaritae*	Valvalyak Formation
							2	*Neoschwagerina margaritae*			
		Murgabian	*Neoschwagerina craticulifera*	Gnishik	*Eopolydiexodina persica*		Members1	*Eopolydiexodina*		Deire Member *Verbeekina*	
			Neoschwagerina simplex	Asni	*Praesumatrina*			*Schwagerina quasifusulini formis*	Kubergandy Formation	*Praesumatrina*	Daraitang Formation
		Kubergandian	*Cancellina cutalensis*		*Cancellina*					*Cancellina cutalensis* *Paraceltites*	Gundara Formation *Armenina* *Misellina ovalis*
			Misellina ovalis *Armenina*		*Armenina*						
	Lower	Bolorian	*Misellina parvicostata*	Davalu	*Misellina parvikostata*				Kochusu, Shindy	*Misellina parvicostata*	Safetdaron Formation
			Brevaxina dyhrenfurthi		*Brevaxina dyhrenfurthi*			*Darvasites* cf. *ordinatus*		*Misellina intermedia*	*Brevaxina dyhrenfurthi*
		Yakhtashian	*Chalaroschwagerina vulgaris*								Chemchi
			Chalaroschwagerina solita								*Chalaroschwagerina vulgaris*

Table 1. (Contd.)

Southern Primor'e (Kotlyar *et al.*, 1990; Zakharov and Oleinikov, 1994)		Japan, Kitakami (Ehiro *et al.*, 1986; Ueno, 1992)		China (Sheng and Jin, 1994)		Southern Mongolia (Pavlova *et al.*, 1991)		Salt Range (Jin *et al.*, 1991)		
Lyudyanza Horizon	*Liuchengoceras*	Toyoma Group	*Colaniella parva*	Changhsingian	*Pleuronodoceras Paratirolites Iranites Phisonites*			Zalukh Group	Chhidru	*Cyclolobus*
	Huananoceras Iranites									
	Eusanyangites		*Araxoceras Stacheoceras*	Wuchiapingian	*Sanyangites*					
	Cyclolobus				*Araxoceras Konglingites*					
	Xenodiscus subcarbonarius				*Codonofusiella kwangsiana*					
Chandalaz	*Lepidolina kumaensis*	Kanokura	*Lepidolina*	Lengwuan	*Metadoliolina inviluta*	Solonker Assemblage			Wargal	*Colaniella minima*
	Timorites		*Timorites*							
	Monodiexodina		*Monodiexodina*	Kuhfengian	*Yabeina gubleri*	Zaganula Assemblage				
Gnishik					*Neoschwagerina margaritae*					
	Yakovlevia mammatiformis				*N. craticulifera Afghanella schencki*					
	Daubichites			Xiangboan	*Neoschwagerina simplex*					
					Cancellina neoschwagerinoides					
Abrek	*Primorewia*	Sakamotozawa	*Misellina claudiae*	Luodianian	*Misellina claudiae*	Khovsgolian	*Gobioceras elenae Kolymaella ogonerensis*			Amb Formation
			Brevaxina otakiensis		*Brevaxina dyhrenfurthi*		*Neouddenites orientalis*			
Dunai Horizon			*Paraschwa gerina*	Longlinian		*Monodiexodina linearis*	*Zellia heritschi*			Sardai Formation

Table 2. Correlation of Permian deposits in the Boreal realm

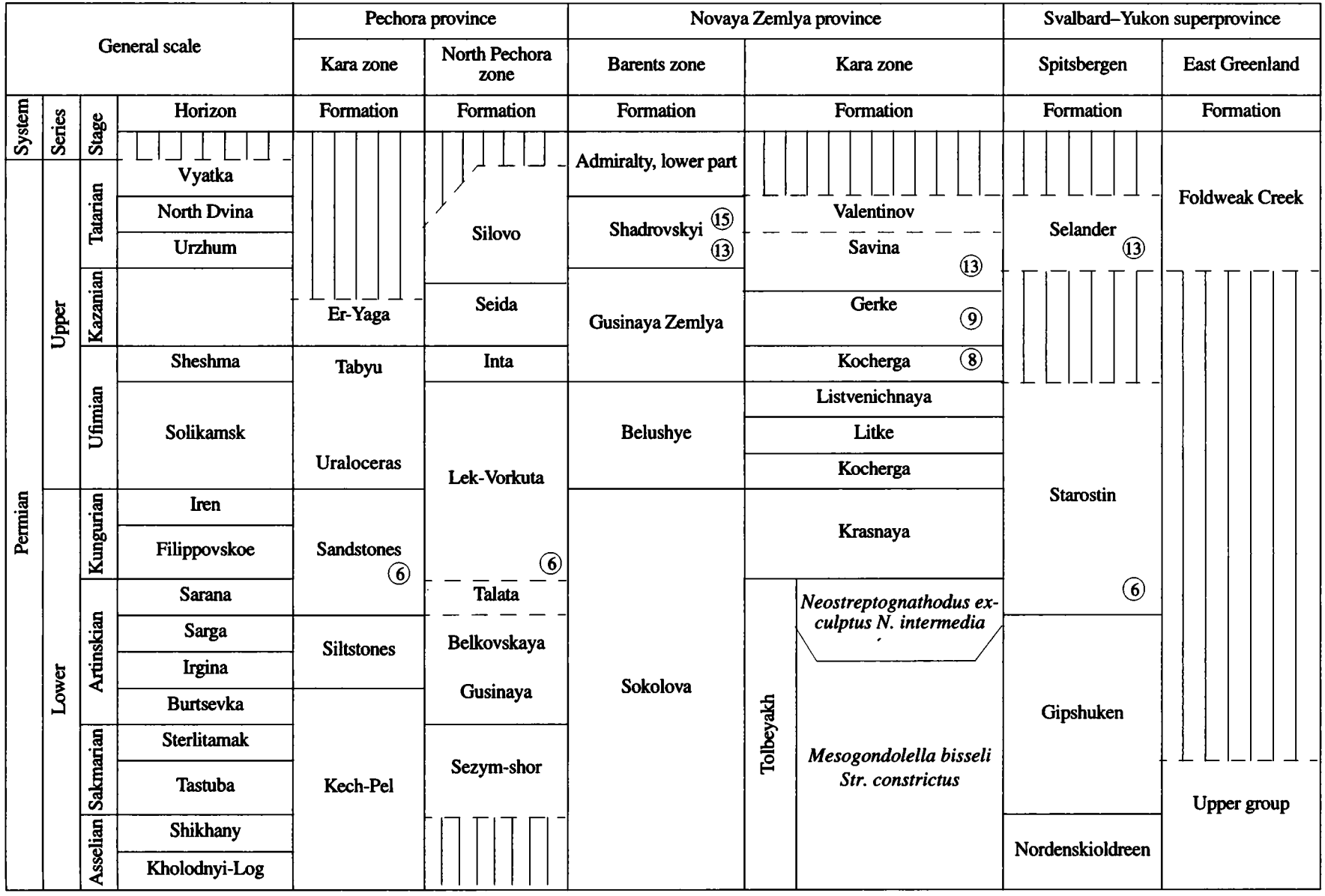
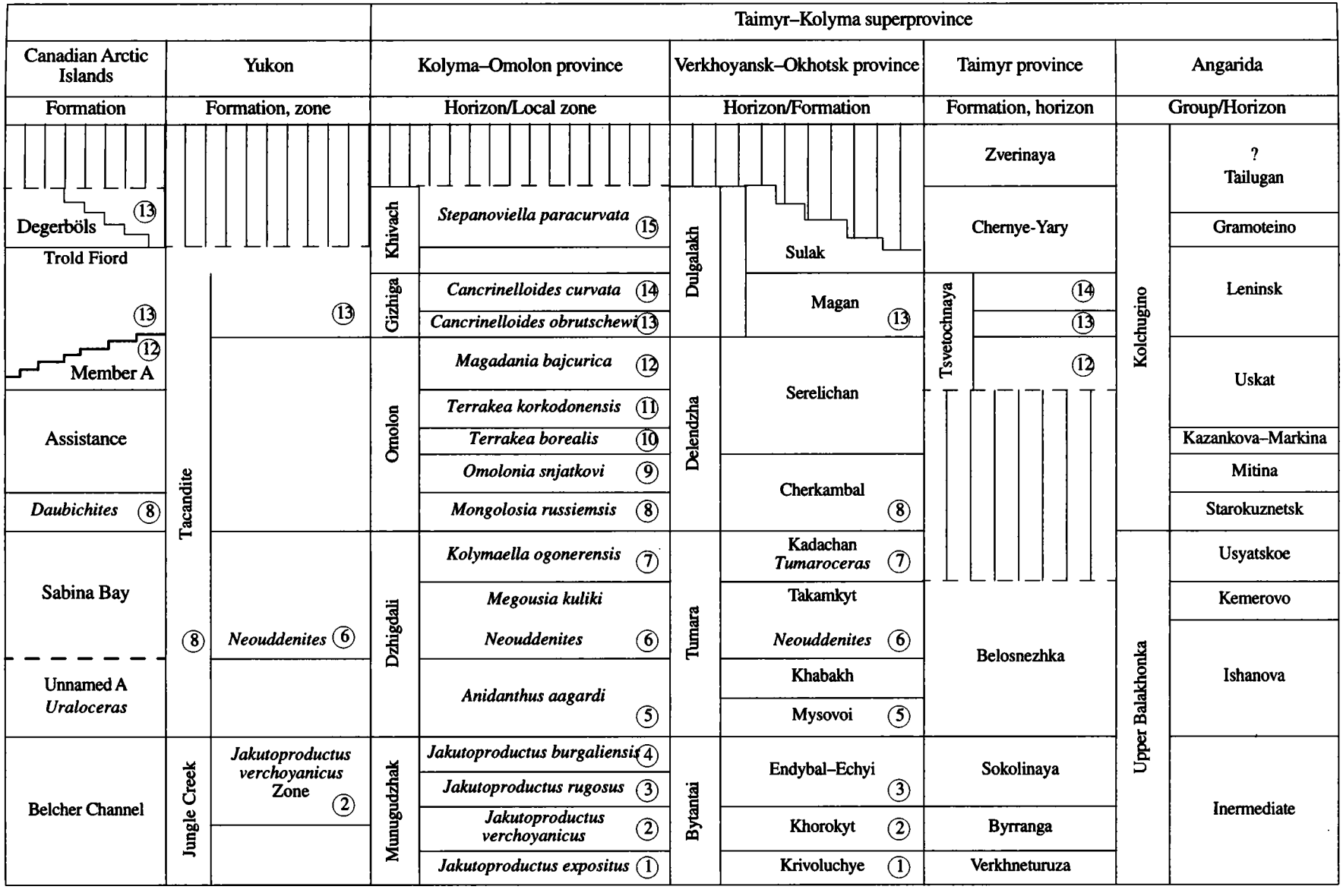


Table 2. (Contd.)



with widespread genera *Arctitreta, Dyoros, Uraloproductus, Yakovlevia, Megousia, Liosotella, Helenaeproductus, Cancrinella, Waagenoconcha,* and *Spirifirella. Tomiopsis, Pseudosyringothyris russiensis* Zav, similar to *Primorewia reshetnikovi* Lich. et Kotl. are also present. Assigning these ammonoids to the Kungurian, it should be noted that most likely the "Kungurian" assemblage is of a wider range and falls outside the scope of the stage.

A similar ammonoid assemblage, or individual but characteristic representatives of it, such as *Neouddenites, Tumaroceras,* and *Uraloceras,* are observed along with the same brachiopod assemblages in the Verkhoyansk region (Andrianov, 1985) and on the Yukon (Nassichuk, 1971; Shi, 1994).

A substantial geodynamic reorganization took place in southern Mongolia in the late Early Permian (Pavlova *et al.*, 1991). As a result of the extensive transgression in the east, spaceous connections were reestablished between the Boreal basin and Paleotethys that promoted the ingress of boreal elements into the latter. The Ural-Pechora (Svalbardian) representative forms (*Arctitreta, Yakovlevia, Megousia, Helenaeproductus, Cancrinella, Liosotella, Waagenoconcha, Ingelarella*) as well as the *Neouddenites* genus typical of this evolutionary stage of the Permian biota, appeared among brachiopods (the Khovsgolian assemblage).

A similar but poorer brachiopod assemblage is present in the Konyushkovo Horizon (= the lower part of the Abrek Horizon) of the southern Primor'e (Kotlyar, 1978).

In the western part of the Boreal realm (basins of eastern Europe, the Urals, Spitsbergen, Islands of Arctic Canada), the Early Permian is characterized by a wide development of fusulinids, colonial corals, and Tethyan brachiopods, which inherited the Carboniferous appearance. Similar faunas of this time were present in basins of the Canadian Arctic Archipelago and Spitsbergen. Another significant change in the biota occurred in the latest Early Permian. Fusulinids, colonial corals, and Tethyan forms among brachiopods almost vanished. Typical assemblages with dominant *Arctitreta, Yakovlevia, Megousia, Anidanthus, Cancrinella, Liosotella, Kochiproductus, Waagenoconcha, Spiriferella, Ingelarella* or *Tomiopsis*, known in the literature as Svalbardian or Pai-Khoi genera, appeared. These genera are known from basins of the Pechora province (the Talata and Lek-Vorkuta formations), Spitsbergen (the Starostin Formation), and the Canadian Arctic Archipelago (in deposits overlying the Belcher Channel Formation).

The exact position of the level discussed is hard to establish in the Permian general scale. As mentioned above, the presence of the Aktastian and "Kungurian" ammonoids in the upper part of the Munugudzhak and the upper zone of the Dzhigdali horizons respectively, suggest this level to be attributed to the upper half of the Artinskian. However, it is hard to tell whether it corresponds to the boundary between the lower and upper Artinskian and the base of the Kungurian, or occurs inside the upper Artinskian. I arbitralily assign this level to the base of the Sarana Horizon as it is just at this level where changes in faunal assemblages occurred and Kungurian elements appeared in some faunal groups (Gorskii, 1984). Guseva points out that by the earliest Kungurian (Sarana Horizon) the whole Artinskian assemblage with the exception of two species (*Healdia panda* Kotsch. and *Macrocypris lenticularis* Coop.) became extinct (Guseva *et al.*, 1968). The Asselian–Artinskian ostracod assemblage inherited many species from the Carboniferous, and since the Sarana time it comprised immigrant forms. All fusulinids, except for individual relict forms of the Nevolin Member, died out at the base of the Sarana Horizon. According to Grozdilova's data, the smaller foraminifer assemblage is similar to the Kungurian rather than to the Artinskian assemblage (Guseva *et al.*, 1968). Conodonts from the upper part of Lower Permian deposits of the Urals and Spitsbergen confirm to some extent the viewpoint adopted. In the Artinskian–Kungurian transitional beds of the western Urals (the Shurtan Formation), which are assigned to the Sarana Horizon, the *Neostreptognathodus pnevi* Zone of conodont scale is distinguished (Brando *et al.*, 1980); the conodont assemblage of the Starostin Formation of Spitsbergen is also attributed to this zone. It turned out later that the *pnevi* Zone is confined not only to the Sarana Horizon but spans the Kungurian as well. At the same time, the distribution of ammonoids in the late Early Permian, according to Bogoslovskaya, is inconsistent with the assignment of the Sarana Horizon, which comprises the late Artinskian ammonoid assemblage, to the Kungurian. This contradiction can hardly be solved at present, because, on the one hand, we are unaware of a clear compliance of the "Kungurian" ammonoid assemblage of the eastern part of the Boreal realm with the Kungurian ammonoids of the Urals, and, on the other hand, typical late Artinskian ammonoids are attributed to the Kungurian in the latest stratigraphic scheme of the Permian deposits of the Urals (*Stratigraficheskie* ..., 1993). Bogoslovskaya argues that the Kungurian in the Urals is "closely related to the Artinskian and cannot be separated from it with any confidence" (Bogoslovskaya, 1984).

Although the correspondence between the discussed biostratigraphic level and the base of the Sarana Horizon is far from beyond doubt, the level at which such a distinct and characteristic change of fossil assemblages takes place is nevertheless well correlative within the whole Boreal realm.

The discussed correlative level is recognizable in the Tethys as well, where it marks an extensive transgression. The onset of the transgression is established ambiguously. Formerly, Leven (1993) related it to the Yakhtashian or Artinskian and later to the late Yakhtashian (Leven, 1994). E.V. Movshovich referred it to the Kungurian, whereas T.A. Grunt regarded it as

varying through time and assumed that in the latest Yakhtashian the transgression spanned the northern margins of the Tethys and later, in the Bolorian, engulfed the peri-Gondwanian sea basins as well.

Analyzing principal events of Permian history, Leven (1993) thoroughly considered the relationship between the Yakhtashian–Bolorian deposits and underlying rocks as well as their dating. It is evident from the analysis that the Yakhtashian deposits are lacking in the greater part of the Tethyan realm (the Vardak and Tesak sections in southern Afghanistan, Iran, Transcaucasia, southeastern Pamir), where deposits with *Misellina* overlie older rock sequences. The southern peri-Gondwanan margin of the Paleotethys, where the transgression began also in the Bolorian, is not an exception, as, according to Leven, the precise dating of transgressively occurring limestones in Tibet is impossible, whereas the transgressive deposits in the northern Karakorum definitely contain Bolorian fusulinids. A similar situation is observed in the southeastern Pamir. In the Kurteke section of this region, the Bazardara Group, the upper limit of which is assigned to the Artinskian (Grunt and Novikov, 1994), is transgressively overlapped by limestones with the Bolorian fusulinids, whereas in the Kastanat–Dzhilga section, the Bazardara Group is overlain by the Kochusu Formation, fully attributed at present to the Bolorian (Leven *et al.*, 1989).

An imperfect dating of the onset of the transgressive cycle is apparently related to difficulties in the subdivision of the late Yakhtashian and early Bolorian fusulinid assemblages. Leven pointed out that "the similarity between the Yakhtashian and Bolorian fusulinid asssemblages does not always offer a definite conclusion on which of these stages we deal with in one or another exposure, and these assemblages are often perceived as indivisible" (Leven, 1993, p. 64). The upper zone of the Yakhtashian is hard to separate from the lower parts of the Bolorian, to be more exact, from the lower parts of the Kochusu Formation on the basis of other fauna as well. For instance, the *Chalaroschwagerina vulgaris* Zone of some sections in Japan comprises conodonts of the *Mesogondonella intermedia–Vjalovognathus shindensis* Zone from the lower parts of the Kochusu Formation, which includes *Mesogondolella bisseli* Clark et Behn., *M. intermedia* (Igo), and *M. asiatica* (Igo), *Pseudohindeodus nassichuki* (Kozur). All species are characteristic of the lower part of the Kochusu Formation (Kozur *et al.*, 1994). When analyzing conodont assemblages of the *vulgaris* Zone of Japan, Movshovich (1986) correlated them with assemblages from the lower part of the Davalu Formation of Transcaucasia, from lower beds of the Chihsian Formation of the Guizhou Province, southern China, (i.e., from the *M. intermedia–M. guioensis* Zone), as well as from the Kungurian Stage.

T.B. Leonova (Leven *et al.*, 1992) also noted the similarity of ammonite assemblages from the lower part of the Kochusu Formation and the *vulgaris* Zone, and indicated that 25 out of 30 species of the Yakhtashian assemblage are found in lower beds of the Kochusu Formation. Common species in these units are *Metalegoceras pamaricum* Leon., *Cardiella pamirica* (Toum.), *Crimites doliaris* Leon., *Prostacheoceras alter* Leon., *Neocrimites dutkevitchi* Pavl., and *Eolegoceras murgabense* Leon. In addition, genera *Agathiceras, Thalassoceras, Shyndoceras,* and *Veruzhites* in the Yakhtashian and Bozterian assemblages are represented by the same species.

Kozur reliably correlated the *Mesogondolella intermedia–Vjalovognathus shindedsis* Zone in lower parts of the Kochusu Formation with the lower zone of the Leonardian Group in western Texas (Wardlaw and Glenister, 1995) and the Chihsian zone in the Chihsian Group of southern China (*Marine Permian ...*, 1994; Wang, 1994) by the presence of common species *Neostreptognathodus exculptus, N. foliatus, Mesogondolella intermedia,* and *M. guioensis*. The presence of *Neostreptognathodus pnevi* in the *M. guioensis–N. exculptus* Zone of North America provided the basis to correlate the lower part of the Kochusu Formation with the base of the Leonardian Group, and both units with the base of the Sarana Horizon of the Urals (Kozur *et al.*, 1994).

As fusulinids are absent from the lower part of the Kochusu Formation, the conodont *M. intermedia–V. shindensis* Zone escapes precise correlation with the fusulinid scale. Thus, it remains unclear whether the conodont assemblage of the *vulgaris* Zone is to be assigned to the Bolorian or, on the contrary, the lower part of the Kochusu Formation is an equivalent of the *vulgaris* Zone of the Yakhtashian. This problem requires further investigation.

The second correlative level of the Permian is more pronounced. It is determined by the appearance of the Roadian ammonoid assemblage and coincides with the beginning of the transgressive–regressive sedimentation cycle. The level is easy to recognize in all biogeographic regions. The sections of the Kolyma–Omolon province are of prime importance for describing the level within the Boreal realm. An extensive transgression is referred here to the Omolon time (Kashik *et al.*, 1990), which marks the accumulation of a carbonate sequence. The boundary between the Dzhigdali and Omolon horizons represents a contrasting biostratigraphic level with an abrupt change in the ammonoid assemblages. The Roadian genera *Daubichites* and *Sverdrupites*, which replaced the Kungurian *Neouddenites, Tumaroceras, Uraloceras,* and *Epijuresanites,* were the first to appear here. The *Kolymia* genus appears in the bivalve assemblage, wheras genera *Mongolosia, Omolonia,* and *Terrakea* of thin-costate linoproductids became dominant among brachiopods.

A similar change of biota is observed in sections of the Verkhoyansk–Okhotsk province at the boundary of the Tumara and Delendzha horizons, as well as in the

Novaya Zemlya province. In the Verkhoyansk–Okhotsk province, the Roadian ammonoids of genera *Daubichites* and *Sverdrupites* appear at the base of the Delendzha Horizon along with the representative brachiopod genus *Mongolosia* and bivalves of the *Kolymia* genus (Andrianov, 1985; Byakov, 1991). Much like in the Taimyr–Kolyma superprovince, the Roadian assemblage replaces the Kungurian ammonoids of *Tumaroceras, Uraloceras,* and *Neouddenites* genera.

In the Novaya Zemlya province, the Roadian assemblage appears in the upper half of the Kocherga Formation and in the lower part of the Gerke Formation. The assemblage is represented by genera *Daubichites, Sverdrupites,* and *Altudoceras* (Bogoslovskaya *et al.*, 1982). The underlying deposits bear abundant *Phylladoderma arberi, Cardiopteris piniformis* and other flora typical of the Pechora Group and indicating that beds with ammonoids cannot be older than the latest Ufimian.

The Roadian ammonoid assemblage is not found west of the Novaya Zemlya province. The assignment of the Roadian event to the mid-Ufimian is confirmed, apart from the data cited above, by the detailed correlation of deposits. Many brachiopod zones established by Ganelin (Kashik *et al.*, 1990) in the Kolyma–Omolon province are traced within the whole Boreal realm, including southern Mongolia. This is especially true in regard to the marginal zones of the Dzhigdali (the *Kolymaella ogonerensis* Zone) and Omolon (the *Mongolosia russiensis* Zone) horizons. The Roadian ammonoid assemblage is confined to the *Mongolisia russiensis* Zone. The *Kolymaella ogonerensis* Zone has been determined recently in upper beds of the Ufimian in the stratotype area of the Solikamsk Horizon. Kotlyar and Ganelin (1989) pointed out earlier that the range of the Kungurian ammonoid assemblage goes beyond the Kungurian. For instance, forms of the Kungurian genus *Uraloceras* were found in marine analogs of the Solikamsk Horizon in the middle part of the Tabyu Formation in Pai-Khoi (Gus'kov *et al.*, 1980), whereas species of the *Tumaroceras* genus occur in the Kadachan Formation underlying the Cherkambal Formation with the Roadian ammonoid assemblage (*Stratigraficheskii slovar'...*, 1977). The *Kolymaella ogonerensis* Zone, revealed in southern Mongolia (Pavlova *et al.*, 1991), yielded the species *Gobioceras elenae*, which is, according to Bogoslovskaya (Bogoslovskaya and Pavlova, 1988), undoubtedly Kungurian in age and coexists with the *Epijaresanites* genus. In her opinion, precisely *Gobioceras* forms were ancestors of the Roadian genus *Spirolegoceras*. In underlying deposits, *Neouddenites orientalis* Bog. was found in association with the Khovsgolian brachiopod assemblage of the *Megousia kulikii* Zone. Thus, a similar change in the Kungurian and Roadian ammonoid assemblages occurs in two boundary brachiopod zones of the Kolyma–Okhotsk province and southern Mongolia. Taking into account that the Roadian ammonoid assemblage directly replaces the Kungurian, the last representatives of which are present in beds identical to the Solikamsk Horizon, the appearance of the Roadian assemblage should be related to the second half of the Ufimian, most likely to Sheshma time. If it is remembered that genera *Spirolegoceras* and *Sverdrupites* are confined to a narrow range, namely, the Roadian, then the *Daubichites* genus seems to exist in younger deposits as well (Sheng and Jin, 1994).

The Roadian ammonoid assemblage is established in the Assistance Formation of the Canadian Arctic Archipelago, which replaces in the section the Sabina Bay Formation referred to the Kungurian (Beauchamp *et al.*, 1989b). The appearance of genera *Daubichites* and *Sverdrupites* is related to the onset of the Assistance transgression (Nassichuk, 1970). It is significant that conodont forms transitional from *Mesogondolella idahoensis* to *M. nankingensis* appear simultaneously with the Roadian ammonoids (Kozur and Nassichuk, 1977), whereas the underlying Sabina Bay Formation is characterized by the presence of *M. idahoensis* only (Beauchamp *et al.*, 1989a).

The Roadian ammonoid assemblage was originally determined in North America in Idaho, Wyoming, and Arizona from the Meade Peak Member of the Phosphoria Formation, where *Daubichites, Spirolegoceras, Glossoceras bramsonorum,* and *Stachecceras exolobatum* were found (Miller and Cline, 1934; Furnish, 1973). Their occurrence, as reported, coincides with the first appearance level of *Mesogondolella nankingensis* marking the lower boundary of the Roadian (Grant and Wardlaw, 1984).

Equivalents of the Roadian deposits are established also in Western Australia, where *Daubichites goochi* (Teichert), *Agathiceras* and *Popanoceras* were recorded in the Lightjack Member of the Liveringa Formation (Glenister and Furnish, 1961).

In the Tethyan realm, the Roadian ammonoid assemblage appears at the base of the Kubergandian deposits (Chediya *et al.*, 1986). It replaces the Bozterian assemblage of the Bolorian, which Bogoslovskaya and Leonova correlate with the Kungurian of the Boreal realm by the level of species evolution. The Bozterian assemblage is reliably correlated with the Roadian by the presence of genera *Epiglyphioceras, Stacheoceras,* and *Paraceltites*, which appeared for the first time in the Roadian assemblage of North America, and genera *Bamyaniceras* and *Popanoceras*, which are not characteristic of the Wordian. The appearance of the Roadian ammonoids *Misselina ovalis,* and *Armenina* in the Kubergandian fusulinid lower zone allows a reliable correlation within the whole Tethys (Table 1). It should be added also that Kozur (personal communication) reported on the appearance of *Mesogondolella nankingensis* in sections of China below beds with *Cancellina.* He considers as invalid data on the first appearance of this species in the *Neoschwagerina craticulifera* Zone.

In North American sections, the Roadian ammonoids appear at the base of the Guadalupian

Group. Thus, if we assume that the Roadian ammonoids appeared simultaneously, then the lower boundaries of such units as the Omolon Horizon and its equivalents in the Boreal realm, the Kubergandian regional stage of the Tethys, and the Roadian regional stage of the American scale can be regarded as synchronous and corresponding to the boundary between the Ufimian Solikamsk and Sheshma horizons in the stratotype section.

The basal level of the Dzhulfinian is of the same order as those already discussed. The lower boundary of this stage is associated with profound evolutionary changes in the composition of ammonoids. Araxoceratids of the *Anderssonoceras, Araxoceras, Protoceras* and many other genera appear for the first time at this level, though the genera *Kingoceras, Timorites*, and *Cyclolobus* still exist along with them in the earliest Djulfian. The lower boundary of the Djulfian is easy to recognize using fusulinids. At the boundary of the *Codonofusiella kwangsiana* Zone identified almost worldwide (China, Transcaucasia, Iran), the schwagerinid–verbeekinid assemblage of fusulinids is replaced by the shubertellid assemblage. Schwagerinids and verbeekinaceans vanish completely, whereas aberrant fusulinids, which appeared earlier, become abundant. Changes in the history of smaller foraminifers are also obvious: formerly dominant hemigordiopsids give way to nodosariids, and specialized genera appear (Kotlyar *et al.*, 1989). Considerable changes in coral associations were especially pronounced in the western Tethyan realm, where "waagenophylloid" fauna was replaced by "pleurophylloid." The appearance of *Araxothyris* in brachiopod assemblages is another very characteristic feature.

Changes in radiolarian assemblages also took place. In addition to the appearance of the *Neoalbaillella* genus, the abundance of representatives of the *Follicuculus* genus decreased abruptly (Rudenko, 1991).

The lower boundary of the Djulfian in the stratotype conodont succession is established at present according to data of Pyatakova (1983), and confirmed by Grigoryan (personal communication) by the appearance of *Clarkina "leveni"* Koz., Most. et Fjat. in the *Codonofusialla kwangsiana* Zone (= *Codonofusiella* + *Araxilevis* Beds). This is consistent with a former assumption on the position of the stage boundary at the base of *Araxilevis* Beds, as the *Araxilevis* genus appears simultaneously with a mass appearance of *Codonofusiella* (Kotlyar *et al.*, 1983) in the Akhura Zone (condensed section). The absence of *Araxilevis* in the Dorasham-2 stratotype section seems to be a result of facies factor. According to present assumptions, the forms identified by the mentioned authors, as, for instance, *Clarkina leveni*, may be identical to *Clarkina postbitteri* Mei et Wardlaw or *Cl. dukouensis* Mei et Wardlaw identified recently in the lower Djulfian beds in Iran (The Iranian-Chinese Research Group, 1995).

A similar situation is observed in sections of China (Sheng Jin-zhang and Jun Yugan, 1994), where the base of the Wuchiapingian or that of the Lopingian is recognized by the appearance of conodonts *Clarkina postbitteri*. Abundant *Codonofusiella* forms, markers of the *Codonofusiella kwangsiana* Zone, are confined to the same level. It should be noted that such genera as *Paraceltites, Doulingoceras, Roadoceras*, and *Altudoceras* along with a complete absence of araxoceratids are recorded in some sections of China in deposits referred to the lower part of the Wuchiapingian (the uper part of the Douling Formation; Zhou, 1994). The *Clarkina postbitteri* species appears simultaneously with the mentioned ammonoids, whereas *Clarkina leveni* along with araxoceratids is present only in the mid-Wuchiapingian. The two-unit structure of the Wuchiapingian is evident as faunal assemblages of upper and lower parts differ greatly. It is not improbable that the Djulfian may also be subdivided into two parts after the revision of all conodonts from beds underlying the *Araxoceras* Zone.

In the Boreal realm, a level at which marine sedimentation is replaced by continental, corresponds to the lower boundary of the Djulfian (Sadovnikov and Orlova, 1994). In the Russian platform, according to data obtained recently, the Vyatka Horizon is correlative with the Djulfian by palynological assemblages.

Thus, these significant changes in the composition of faunal assemblages of different groups allow them to be considered as global correlative levels.

Other levels of a lower order can also be distinguished, but require further study. A level corresponding to the mid-Permian maximum transgression, which began in the Roadian (the *Doubichites* Zone), should be mentioned first of all. In the Boreal realm, this level is consistent with the boundary between the *Omolonia snjatkovi* and *Terrakea borealis* Zones identified in the Taimyr–Kolyma superprovince. The *Daubichites* or Roadian ammonoid assemblages abruptly died out at this level, whereas brachiopod genera *Terrakea, Orulgania,* and *Tumarinia* were progressing. The *Terrakea* genus is very similar, if not identical, to the Wordian genus *Grandaurispina*, and the genera *Orulgania* and *Tumarinia* are compatible with the Kazanian genus *Licharewia* as was noted earlier. The Kazanian ingression into the East European province was most likely a consequence of the northern extensive transgression of the mid-Omolonian time (Kashik *et al.*, 1990). There is no data for a direct correlation of the Kazanian with the *Terrakea* Zones of the Omolon Horizon and their analogues in the Boreal realm. Nevertheless, the evolutionary level of brachiopods along with a certain similarity of smaller foraminifers (Kashik *et al.*, 1990) and bryozoans (Morozova, 1981) permit an arbitrary correlation of the Kazanian and the Omolon Horizon (without the two lower zones) with the Murgabian and Wordian regional stages of the Tethys and North America to be made. The goniatite of the *Altudoceras* genus found at

the base of the Kazanian, which was identified earlier as *Pseudogastrioceras* (Kulikov *et al.*, 1973) and recognized by Pavlova to be similar to early Wordian species, suggest synchronism of these units.

A part of the Assistance Formation of the Canadian Arctic Archipelago bearing *Terrakea* (Waterhouse, 1971) and the overlying Member A with rare *Magadania*, as well as the lower part of the Trold Fiord Formation can be correlated indubitably with the Kazanian and the larger upper part of the Omolon Horizon.

The Early Permian maximum of transgression in the Tethys falls on the *Neoschwagerina craticulifera–Afghanella schenki* Zone clearly recognized within the whole realm. The Wordian genus *Waagenoceras*, which marks the lower boundary of the stage, appears at the base of the zone. In Sicily, *Waagenoceras* is known to occur along with *N. craticulifera*. The extinction of the most representative genera of the Roadian assemblage is also related to the base of the *N. craticulifera* Zone. New data gained in the Crimea indicate that typical Wordian genera are still absent in the *Neoschwagerina simplex* Zone and appear in the *N. craticulifera* Zone (Zakharov, personal communication). The coexistence of some Kazanian bryozoans of genera *Gyrtipora* and *Gyrtiporina* with *Neoschwagerina craticulifera* and the Il'inian (Kazanian) flora in deposits of the Vladivostok Horizon in southern Primor'e is very characteristic (Kiseleva, 1986). A similarity of brachiopod and bryozoan assemblages of the Vladivostok Horizon with those of the Tsaganul Horizon of southern Mongolia is also remarkable (Pavlova *et al.*, 1991). The horizons yielded common genera of boreal brachiopods (*Arctitreta, Kochiproductus, Waagenoconcha, Liosotella, Yakovlevia, Megousia, Spiriferella, Alispiriferella,* and *Kaninospirifer*) as well as bryozoans.

According to the foregoing consideration, the reliable correlation level is defined by the lower boundaries of the *Waagenoceras* ammonite genozone and the *Neoschwagerina craticulifera–Afghanella schencki* fusulinid zone. The use of interchangeable features and successive correlations most likely indicate the compliance of this level with the bases of the Kazanian in the Russian platform, the *Terrakea borealis* Zone and its analogues in the Boreal realm, as well as with the boundary between the *Neoschwagerina simplex* and *N. craticulifera* Zones in the Tethys, and the base of the Wordian regional stage in North America (Table 3).

Until recently, the lower boundary of the Midian, identified by the appearance of the *Yabeina* genus of evolved fusulinids and the *Timorites* genus of ammonoids, was recognized as a reliable correlative level (Leven, 1975). A division of the Midian into two parts and a perceptible boundary in its middle part were also noted (Leven, 1980; Kotlyar, 1993). Species of the *Yabeina* genus found with abundant assemblages of Wordian ammonoids in Keich Creek Beds in western Canada (Ross and Nassichuk, 1970) and Sicily caused the revision of the volume, dating, lower boundary position and correlation of the Midian. It should be stated that there is no good reason to retain this stage futher, as it is characterized by very different ammonoid assemblages, the more so as the author of the stage also disputes the affiliation of its upper part (the *Lepidolina kumaensis* Zone) to the Midian.

At the same time, the boundary of upper Midian deposits, marked by the appearance of the Capitanian zonal genus *Timorites*, is acknowledged to be one of the most distinct and traceable worldwide. When analyzing the Midian deposits in the Tethyan realm, Leven (1993) pointed out their wide distribution, yet his analysis suggests the transgressive occurrence of upper but not lower Midian deposits. This is true for the Kitakami sections in Japan, the Chandalaz Horizon in Primor'e, the Kaftarmol and Kafirbacha formations in Darvaz, the Wargal Formation in the Salt Range, etc. Lower Midian deposits make up a single, hardly divisible carbonate group with the Murgabian. This is evident from the Akiyoshi, Atetsu, Akasaka and Omi sections in Japan (Minato *et al.*, 1978), and also from Transcaucasia (Kotlyar *et al.*, 1989), central Iran (Taraz, 1970), and the Elburz Mountains (Stepanov *et al.*, 1989).

The appearance of the *Timorites* genus, which marks the lower boundary of the Capitanian deposits in America and the upper Midian deposits in the Tethyan realm, is noted in the *Lepidolina minatoi* Zone, which also comprises *Lepidolina kumaensis*, in the Iwaizaki Formation of Japan (Ehiro *et al.*, 1986), at the boundary between the *Monodiexodina sutschanica* and *Parafusulina stricta* zones of the Chandalaz Horizon of southern Primor'e (Kotlyar *et al.*, 1989), and further in the Maokou Group of China (Liang, 1983), the Abadeh Formation of Iran (Ehiro *et al.*, 1986), the Basleo Beds of Timor Island (Haniel, 1915; Wanner, 1932), and the Osakhta Formation of the Amur River area (Ruzhentsev, 1955). This worldwide appearance of the *Timorites* genus is accompanied by *Stacheoceras* and less abundant *Neogeoceras* and *Roadoceras* genera. The less evident changes in fusulinid assemblages are assigned to the top of the *Neoschwagerina margaritae* Zone, which is attributed to the Murgabian (Baud *et al.*, 1993) despite the presence of representatives of the *Yabeina* genus and other foraminifers of the Midian age. The appearance of the *Timorites* genus coincides with that of the smaller foraminifer assemblage of the *Baisalina pulchra* Zone. In the conodont succession, *Mesogondolella postserrata* appears at this level.

In the Boreal realm, a similar correlative level is identified at the base of the Gizhiga Horizon of the Kolyma–Omolon region and the Togotui Horizon of Transbaikalia. Their compliance with upper Midian deposits of the Tethys and Capitanian deposits of North America is based on findings of ammonoids of the *Timorites* genus in the *Cancrinelloides obrutshewi* Zone of the Togotui Formation (Okuneva and Zakharov, 1992) and representative bivalve species

Table 3. Correlation of Permian regional scales

General scale			Regional scale for the East Europe	Regional scale for the eastern Boreal realm (Ganelin, 1984; Sadovnikov and Orlova, 1994)	Regional scale for the Tethys (Leven, 1980, 1993)		Regional scale for China (Sheng *et al.*, 1994)		Regional scale for Japan (Minato *et al.*, 1978; Jin *et al.*, 1994)		Regional scale for North America (Ross and Ross, 1987; Jin *et al.*, 1994)	
System	Series	Stage	Horizon	Horizon, regional stage	Series	Regional stage	Series	Regional stage	Series	Regional stage	Series	Regional stage
Permian	Upper			Taimyrian	Upper	Dorashamian	Lopingian	Changhsingian	Toyoma	Nabekoshi	Ochoan	
		Tatarian	Vyatka			Djulfian		Wuchiapingian		Maehama		
			Northern Dvina	Khivachian		Midian	Yangsingian	Lengwuan	Kanokura	Iwaizaki	Guadalupian	Capitanian
			Urzhum	Gizhigian						Kattisawa		
		Kazanian		Omolonian		Murgabian		Kuhfengian		Akasaka		Wordian
		Ufimian	Sheshma			Kubergandian		Xiangboan				Roadian
	Lower		Solikamsk	Dzhigdalinian	Lower	Bolorian		Luodianian		Nabeyama	Omolonian	Cathedralian
		Kungurian	Iren									
			Filippovskoe						Sakamotozawa	Kabayama		Hessian
		Artinskian	Sarana									
			Sarga	Munugudzhakian		Yakhtashian	Chuanshanian	Longlinian;		Kawagushi	Wolfcampian	Lenoxian
			Irgina									
			Burtsevka									
		Sakmarian	Sterlitamak			Sakmarian						
			Tastuba					Zisongian				
		Asselian	Shikhany			Asselian				Nagato		Nealian
			Kholodnyi Log									

Maitaia bella Biax. in the Gizhiga Horizon. An assemblage comprising *Timorites siggilarius* Ruzh. and *Maitaia bella*, as well as diverse bryozoans of the *Parafusulina stricta* and *Lepidolina kumaensis–Metadoliolina lepida* zones of the Chandalaz Horizon of the southern Primor'e are found in the middle unit of the Osakhta Formation of the Amur River area. Besides, a zonal species *Cancrinelloides obrutshewi* of the Gizhiga Horizon is found in the Koryak Highland in association with the late Midian fusulinids *Yabeina globosa* and *Lepidolina multiseptata* (Epshtein *et al.*, 1985).

A lesser diversity of faunal assemblages is very characteristic of the level. The brachiopod assemblages changed in this manner in the Boreal realm. The diverse thin-costate lynoproductid assemblage with *Terrakea* and *Magadania* gives way to an extremely uniform assemblage of *Cancrinelloides, Spitzbergenia* and rare strophaloziids. An abrupt impoverishment of assemblages is recognized at this level in other biogeographic areas (Jin *et al.*, 1994).

Paleomagnetic data play an important part in the correlation of Upper Permian deposits. The study of paleomagnetic properties of Permian deposits either in the Boreal or in the Tethyan realms failed to reveal the exact position of the boundary between the Kiama and Illawarra zones, which can be used as an important control marker for global correlations of deposits different in facies. Nevertheless, in all the Tethyan and peri-Gondwanan sections, the position of variable-polarity zones is recognized approximately at the same level near the base of the upper Midian, e.g., in the upper part of the *Chusenella abichi* Zone of Transcaucasia (Kotlyar *et al.*, 1984), at the base of the Kutal Member of the Gan Formation of the southeastern Pamir (Davydov *et al.*, 1982) and the Khamtarma Formation of the northern Pamir (Novikov *et al.*, 1991), in the upper part of the Vladivostok Horizon of the southern Primor'e (Zakharov and Sokarev, 1991), in the upper part of the Maokou Formation and in the basal beds of the Wargal Formation of the Salt Range (Jin *et al.*, 1994). The variable-polarity zones are determined at a nearly similar level in the Boreal realm as well, namely in the middle part of the Gizhiga Horizon (Kashik *et al.*, 1990) and the Shadrovskii Formation of Novaya Zemlya (Gurevich and Slautsitais, 1988), and in the upper part of the Rotliegende of central Europe (Menning, 1988). In North America, a zone of normal polarity is identified near the base of the Yates Formation, which corresponds, according to Menning (1988), to the middle part of the Capitanian. Taking into account that the boundary between the Kiama and Illawarra hyperzones in the Russian platform lies in the upper part of the Urzhum Horizon of the Tatarian, it may be suggested that the upper Midian and Capitanian deposits correspond to the Tatarian.

The tracing of these correlative levels in continental deposits of Angarida can be made arbitrarily through paralic and riparian sections of the Pechora, Taimyr, Kolyma–Omolon, Verkhoyansk–Okhotsk and Far East provinces, as well as in Mongolian sections.

By the presence of some common taxons within the Barda and Ishanovo floral assemblages, Naugolnykh (1993) correlated the level of first appearance of the Barda flora in the western Urals with the base of the Ishanovo Horizon of Angarida. His conclusion fully confirmed the correlation scheme of marine and continental deposits inferred earlier (Kotlyar and Ganelin, 1989). The mixed subtropical Barda flora replaced the xerophytic flora of Eurameria. Similar changes took place in the composition of the Lek-Vorkuta flora of the Pechora region, which is confirmed by the appearance of diverse Musci species, the representative elements of the cordaites forest formation (Burago, 1986).

In the southern Primor'e, a significant change in flora is recognized in the earliest Abrek time, when Catasian flora expanded into this territory. The confinement of marine interlayers with the Konyushkovo brachiopod assemblage to this interval amply confirms correlations based on fauna and flora, as well as the inferrence on climatic warming at the time of transgression. In China, according to Burago (1986), the early Shihhotse flora corresponds to the Abrek flora.

Kubergandian (Roadan) deposits may correspond to the formation time of pteridophyte–pteridosperm–cordaites flora, and their lower boundary is comparable with the boundary between the Verkhnebalakhonka and Kolchugino Groups. Early elements of Kolchugino flora appear in boreal sections in the *Mongolosia russiensis* Zone of the Omolon Horizon of the Kolyma–Omolon province. The confinement of the Roadian ammonoids to this zone allows a correlation of the boundary between the Verkhnebalakhonka and Kolchugino groups of Angarida with the boundary between the Dzhigdali and Omolon horizons, and also with the boundary between the Solikamsk and Sheshma horizons of the Ufimian that is in agreement with the earlier statement by Meyen (1984). A change in the flora of the Primor'e region is recognized nearly at the same level (the boundary between the Abrek and Vladivostok horizons), where the abundance of cordaites decreases abruptly and pteridosperms and ferns become dominant (Burago, 1986). Many paleobotanists refer the appearance of cordaites to the earliest Kazanian (Burago, 1986; Durante, 1994).

When the level of the normal polarity zones (in sections from which the linkage of the Kiama and Illawarra zones is missing) in the Boreal realm, Tethys, Angarida and in the type locality on the Russian platform is considered to be synchronous, then the lower boundaries of the upper Midian and Capitanian deposits can be brought into coincidence with the base of the Leninsk Horizon of Angarida, as the lower boundary of the Illawarra hyperzone is established in the middle part of the horizon (Meyen, 1984). This possibility is supported by some floral data. Sulcate cordaites and seeds, which are characteristic of the Gramoteino and Tailugan horizons,

are found in upper Midian deposits of the southern Primor'e (the Sicinian flora of the Chandalaz Horizon).

Foster and Jones (1994) distingished a significant correlative level, marked by the appearance of miospores *Scutisporites unicus* Klaus and *Playfordiaspora cancellosa* (Playford et Dettmann) Maheshwari et Banerji, which they mistakenly related to the first occurrence of *Lueckisporites virkkiae* Potonié et Klauss at the base of the Tatarian. On this ground, they correlated the Chiddru Formation of the Djulfian with the Tatarian of the general scale in the whole range. Gomankov (1994) provided strong evidence that only the uppermost Tatarian, and most likely only the Vyatka Horizon, corresponds to the Djulfian. As a whole, the Djulfian as well as probably the Dorashamian of the Tethys are correlated, in addition to the uppermost Tatarian, with a part of the volcanosedimentary sequence of the Siberian platform distinguished as the "Taimyrian" (Sadovnikov and Orlova, 1994).

CONCLUSION

The interregional correlations allowed a series of principal correlative levels to be distinguished as traceable worldwide.

The first of them reflects a significant paleogeographic event and is related to the extensive transgressions. This is one of the contrasting biostratigraphic boundaries, which is marked by basal levels of the *Neostreptognathodus pnevi* Zone of the conodont scale in the Urals, the *Mesogondolella guioensis–Neostreptognathodus exculaptus–N. pnevi* Zone in America, and the *M. guioensis–N. exculptus* Zone in the Tethys. This enables the lower boundaries of the Sarana Horizon of the Artinskian in the western Urals, the Dzhigdali Horizon and its analogues in the Boreal realm, the Bolorian in the Tethys (Leven, 1980), and the Leonardian Group in America to be considered as synchronous.

The second reference level marked by the onset of the mid-Permian transgression is determined by the appearance of the representative Roadian ammonoid assemblage often called in the Boreal realm the *"Daubichites"* assemblage. It is traced worldwide at the base of the *Mesogondolella nankingensis* conodont zone, and corresponds to the basal boundaries of the Kubergandian regional stage of the Tethys, the Omolon Horizon and its analogues in the Boreal realm, and also to the boundary between the Solikamsk and Sheshma Horizons of the Ufimian of the general scale in the stratotype section, and the base of the Guadalupian Group or the Roadian Stage in America.

The third level at the base of the Djulfian is marked by the appearance of araxoceratids and the conodont form *Clarkina leveni*; it also corresponds to the lower boundary of the *Codonofusiella kwangsiana* fusulinid zone. The level is traced mainly in the Tethys. In the Boreal realm, it is correlated with a level at which the marine sedimentation is replaced by the continental. In the Russian platform, the data available permit a rough position of the lower Djulfian boundary to be in the upper Tatarian.

The low-order correlative levels reflect less pronounced biostratigraphic events and are determined mainly by changes in ammonoid and conodont assemblages.

ACKNOWLEDGMENTS

The work was supported by the International Science Foundation (grant no. SV-000) and by the International Science Foundation in collaboration with the government of the Russian Federation (grant no. SV-300).

Reviewers M.F. Bogoslovskaya and T.A. Grunt

REFERENCES

Andrianov, V.N., *Permskie i nekotorye kamennougol'nye ammonoidei Severo–Vostoka Azii* (Permian and Certain Carboniferous Ammonoids of Northeastern Asia), Novosibirsk: Nauka, 1985.

Bando, Y., Bhatt, D.K., Gupta, V.J., *et al.*, Some Remarks on the Conodont Zonation and Stratigraphy of the Permian, *Rec. Res. Geol.*, 1980, vol. 8, pp. 1–35.

Baud, A., Marcoux, J., Guiraud, R., *et al.*, Late Murgabian Map and Paleoenvironments of the Tethys, *Permophiles*, 1993, no. 22, pp. 18–19.

Beauchamp, B., Harrison, J.C., and Henderson, C.M., Upper Paleozoic Biostratigraphy and Basin Analysis of the Sverdrup Basin, Canadian Arctic Archipelago: Part 1. Time Frame and Tectonic Evolution, *Bull. Can. Pet. Geol.*, 1989a, vol. 19, no. 1, pp. 105–113.

Beauchamp, B., Harrison, J.C., and Henderson, C.M., Upper Paleozoic Stratigraphy and Basin Analysis of Sverdrup Basin, Canadian Arctic Archipelago: Part 2. Transgressive–Regressive Sequences, *Ibid.*, 1989b, pp. 115–124.

Bogoslovskaya, M.F., Ammonoids, in *Osnovnye cherty stratigrafii permskoi sistemy SSSR* (Basic Features of the Permian Stratigraphy of the USSR), Leningrad: Nedra, 1984, pp. 248–257.

Bogoslovskaya, M.S. and Pavlova, E.E., On the Evolution of Ammonoids of the Spirolegoceratidae Family, *Paleontol. Zh.*, 1988, no. 2, pp. 111–114.

Bogoslovskaya, M.F., Ustritskii, V.I., and Chernyak, G.E., Permian Ammonoids from Novaya Zemlya, *Paleontol. Zh.*, 1982, no. 4, pp. 58–67.

Burago, V.I., On the Boundary Between the Angara and Catasian Floral Kingdoms, *Permsko–triasovue sobytiya v razvitii organicheskogo mira Severo-Vostochnoi Azii* (Permian–Triassic Events in Biota Evolution in Northeastern Asia), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1986, pp. 6–23.

Byakov, A.S., Stratigraphy and Bivalves of Permian Deposits of the Kolyma River Basin, *Cand. Sci. (Geol.) Dissertation*, Moscow: Moscow State Univ., 1991.

Chediya, I.O., Bogoslovskaya, M.F., Davydov, V.I., and Dmitriev, V.Yu., Fusulinids and Ammonoids of the Kubergandian Stratotype (Southeastern Pamirs), *Ezheg. Vses. Paleontol. O-va*, 1986, vol. 29, pp. 28–58.

Davydov, V.I., Komissarova, R.A., Khramov, A.N., and Chediya, I.O., On the Paleomagnetic Characteristics of Upper Permian Deposits of the Southeastern Pamirs, *Dokl. Akad. Nauk SSSR,* 1982, vol. 267, no. 5, pp. 1177–1181.

Durante, M.V., Late Paleozoic Floras of Angarida (The Paleoecosystem Approach, Climate Reconstructions), *Ekosistemnye perestroiki i evolyutsiya biosfery* (Ecosystem Reorganizations and Evolution of the Biosphere), Moscow: Nedra, 1994, pp. 248–257.

Echiro, M., Shimoyama, Sh., and Murata, M., Some Permian Cyclolobaceae from the Southern Kitakami Massif, Northeast Japan, *Trans. Proc. Paleontol. Soc. Jpn., New Ser.*, 1986, no. 142, pp. 400–408.

Epstein, O.G., Terekhova, G.P., and Solov'eva, M.N., The Paleozoic of the Koryak Highland (Foraminifer Fauna, Biostratigraphy), *Vopr. Mikropaleontol.*, 1985, no. 27, pp. 47–76.

Foster, C.B. and Jones, P.J., Correlation Between Australia and the Type Tatarian, Russian Platform, Evidence from Palynology and Conchostraca: A Discussion, *Permophiles,* 1994, no. 24, pp. 36–43.

Furnish, W.M., Permian Stage Names, *Mem. Can. Soc. Pet. Geol.,* 1973, no. 2, pp. 522–548.

Ganelin, V.G., The Taimyr–Kolyma Superprovince, *Osnovnye cherty stratigrafii permskoi sistemy SSSR* (Basic Features of the Permian Stratigraphy of the USSR), Leningrad: Nedra, 1984, pp. 111–123.

Glenister, B.F. and Furnish, W.M., The Permian Ammonoids of Australia, *J. Paleontol.,* 1961, vol. 35, no. 4, pp. 673–736.

Gomankov, A.V., Palynological Correlation of the Type Tatarian: Continuing the Discussion, *Permophiles,* 1994, no. 25, pp. 33–35.

Gorskii, V.P., Alekseeva, I.A., Vladimirovich, V.P., *et al.*, The East European Province, in *Osnovnye cherty stratigrafii permskoi sistemy SSSR* (Basic Features of the Permian Stratigraphy of the USSR), Leningrad: Nedra, 1984, pp. 29–75.

Grant, R.E. and Wardlaw, B.R., Redefinition of Leonardian–Guadalupian Boundary in Regional Stratotype for Permian of North America, *Proc. 27th Int. Geol. Congr.,* Moscow, 1984, p. 52.

Grunt, T.A. and Novikov, V.P., Biostratigraphy and Biogeography of the Early Permian in the Southeastern Pamirs, *Stratigr. Geol. Korrelyatsiya,* 1994, vol. 2, no. 4, pp. 28–37.

Gurevich, E.L. and Slautsitais, I.P., Paleomagnetic Records in Upper Permian and Lower Triassic Deposits of Admiralty Peninsula, Novaya Zemlya, *Izv. Akad. Nauk SSSR, Ser. Geol.,* 1988, no. 1, pp. 102–110.

Gusev, E.A., Grozdilova, L.P., and Gorskii, V.P., Biostratigraphic Substantiation of the Artinskian–Kungurian Boundary in the Urals, *Dokl. Akad. Nauk SSSR,* 1968, vol. 182, no. 4, pp. 893–895.

Gus'kov, V.A., Pukhonto, S.K., and Yatsuk, N.E., Upper Permian Deposits of Northeastern Pai-Khoi, *Sov. Geol.,* 1980, no. 2, pp. 68–75.

Haniel, C.A., Die Cephalopoden der Dyas von Timor, *Paleontol. Timor,* 1915, vol. 3, no. 6, p. 153.

Iranian-Japanese Research Group. The Permian and the Lower Triassic Systems in Abadeh Region, Central Iran, *Mem. Fac. Sci. Kyoto Univ., Ser. Geol. Mineral.,* 1981, vol. 47, no. 2, p. 133.

Jin Yugan, Glenister, B.F., Kotlyar, G.V., and Sheng Jinzhang, An Operational Scheme of Permian Chronostratigraphy, *Palaeoworld 4,* Nanjing Univ. Press, 1994, pp. 1–13.

Jin Yugan, Sheng Jin-zhang, Glenister, B.E., *et al.*, Revised Operational Scheme of Permian Chronostratigraphy, *Permophiles,* 1994, no. 25, pp. 12–15.

Jin Yugan, Zhang Jing, and Shang Qinghua, Two Phases of the End-Permian Mass Extinction, *Mem. Can. Soc. Pet. Geol.*, 1994, no. 17, pp. 813–822.

Kashik, D.S., Ganelin, V.G., Karavaeva, N.I., Byakov, A.S., *et al.*, *Opornyi razrez permi Omolonskogo massiva* (The Permian Reference Section of the Omolon Massif), Leningrad: Nauka, 1990.

Kiseleva, A.V., Late Permian Bryozoans of the Vladivostok Horizon in Primor'e, *Permsko–triasovye sobytiya v razvitii organicheskogo mira severovostochnoi Azii* (Permian–Triassic Events in Biota Evolution in Northeast Asia), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1986, pp. 48–56.

Kotlyar, G.V., Correlation of Upper Permian Deposits of Southern Primor'e with Coeval Sequences of the Tethyan and Boreal Realms, in *Verkhnii paleozoi severovostochnoi Azii* (The Upper Paleozoic of Northeast Asia), Vladivostok: Dalnevost. Nauch. Tsentr Akad. Nauk SSSR, 1978, pp. 5–23.

Kotlyar, G.V., Subdivision and Correlation of the Upper Permian of the Tethys and Circum-Pacific Region, *Tikhookean. Geol.*, 1993, no. 4, pp. 7–20.

Kotlyar, G.V. and Ganelin, V.G., The Permian: Interregional Correlation of Stratified Deposits and the History of Sedimentation in the USSR, in *Geologicheskoe stroenie i mineral'geniya SSSR* (Geological Structure and Metallogeny of the USSR), Leningrad: Nedra, 1989, vol. 10, no. 1, pp. 180–185.

Kotlyar, G.V., Zakharov, Yu.D., Kropacheva, G.S., *et al.*, *Pozdnepermskii etap evolyutsii organicheskogo mira: Midiiskii yarus SSSR* (Late Permian Biota Evolution: The Midian Stage of the USSR), Leningrad: Nauka, 1989.

Kotlyar, G.V., Komissarova, R.A., Khramov, A.N., and Chediya, I.O., Paleomagnetic Characteristics of the Upper Permian Deposits in Transcaucasia, *Dokl. Akad. Nauk SSSR,* 1984, vol. 276, no. 3, pp. 669–674.

Kotlyar, G.V., Kropacheva, G.S., Sosnina, M.I., *et al.*, Zonation of Upper Permian Marine Deposits of Southern Primor'e, in *Novye dannye po biostratigrafii paleozoya i mezozoya yuga Dal'nego Vostoka* (New Data on the Paleozoic and Mesozoic Biostratigraphy of the Southern Far East), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1990, pp. 104–116.

Kotlyar, G.V., Chediya, I.O., Kropacheva, G.S., and Vuks, G.P., The *Codonofusiella* and *Araxilevis* Beds of the Upper Permian Deposits in Transcaucasia, *Dokl. Akad. Nauk SSSR,* 1983, vol. 270, no. 1, pp. 190–195.

Kozur, H., Davydov, V., and Kotlyar, G., Preliminary Report on the Permian Conodont Fauna of SE Pamir and Its Importance for the Permian Time Scale, *Permophiles,* 1994, no. 24, pp. 13–15.

Kozur, H. and Nassichuk, W.W., Permian Conodonts in the Canadian Arctic Archipelago—Biostratigraphic Discussion, *Pap.-Geol. Surv. Can.,* 1977, no. 77-1A, pp. 139–143.

Kulikov, M.V., Pavlov, A.M., and Rostovtsev, V.N., On Goniatite Findings in Lower Kazanian Deposits of Northern Russian Platform, *Dokl. Akad. Nauk SSSR,* 1973, vol. 211, no. 6, pp. 1412–1414.

Leven, E.Ya., Permian Stratigraphic Scale for the Tethys, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1975, vol. 50, no. 1, pp. 5–21.

Leven, E.Ya., *Ob'yasnitel'naya zapiska k stratigraficheskoi shkale permskikh otlozhenii oblasti Tetis* (Explanatory Notes to the Stratigraphic Scale of Peminan Deposits of the Tethyan Realm), Leningrad: Vses. Nauch.–Issled. Geol. Inst. (VSEGEI), 1980.

Leven, E.Ya., Yakhtashian Stage, the Permian: Substantiation, Characteristics, Correlation, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1980, no. 8, pp. 50–60.

Leven, E.Ya., Main Events in Permian History of the Tethys and Fusulinids, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 59–75.

Leven, E.Ya., The Mid–Early Permian Regression and Transgression of the Tethys. Pangea: Global Environments and Resources, *Mem. Can. Soc. Pet. Geol.*, 1994, no. 17, pp. 233–239.

Leven. E.Ya., Dmitriev, V.Yu., and Novikov, V.P., *Ob'yasnitel'naya zapiska k regional'noi stratigraficheskoi skheme permskikh otlozhenii Srednei Azii (Pamirskii subregion)* (Explanatory Notes to the Regional Stratigraphic Scheme of Permian Deposits in Central Asia: The Pamir Subregion), Dushanbe: Donish, 1989.

Leven, E.Ya., Leonova, T.B., and Dmitriev, V.Yu., The Permian of the Darvaz–Transalai Zone of Pamir. Fusulinids, Ammonoids, Stratigraphy, *Tr. Paleontol. Inst. Ross. Akad. Nauk*, 1992, vol. 258, pp. 1–202.

Liang, X., New Material of Permian Ammonoids with Discussion on the Origin, Migration of Araxoceratidae and the Horizon of the Paratirolites, *Acta Palaeontol. Sinica*, 1983, vol. 22, no. 6, pp. 606–615.

Marine Permian in Guizhou and Guangxi: Excursion Guidebook, Guiyang, China, 1994.

Meyen, S.V., Correlation of Permian Deposits of the Angara Region, *Osnovnye cherty stratigrafii permskoi sistemy SSSR* (Basic Features of the Permian Stratigraphy of the USSR), Leningrad: Nedra, 1984, pp. 226–229.

Menning, M., On the Illawarra Reversal, *Permophiles*, 1988, no. 13, pp. 12–16.

Miller, A.K. and Cline, L.M., The Cephalopods of the Phosphoria Formation of Northwestern United States, *J. Paleontol.*, 1934, vol. 8, no. 3, pp. 281–302.

Minato, M., Kato, M., Nakamura, K., *et al.*, Biostratigraphy and Correlation of the Permian of Japan, *J. Fac. Sci. Hokkaido Univ.*, 1978, Ser. 4, vol. 18, pp. 11–47.

Morozova, I.P., *Pozdnepaleozoiskie mshanki Severo–Vostoka SSSR* (Late Paleozoic Bryozoans of the Northeast USSR), Moscow: Nauka, 1981.

Movshovich, E.V., Permian Conodonts of the USSR and Correlation Problems of Permian Deposits of Laurasia, *Korrelyatsiya permo–triasovykh otlozhenii Vostoka SSSR* (Correlation of Permian–Triassic Deposits of Eastern USSR), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1986, pp. 33–49.

Nassichuk, W.W., Permian Ammonoids from Devon and Melvill Islands, Canadian Arctic Archipelago, *J. Paleontol.*, 1970, vol. 44, no. 1, pp. 77–97.

Naugolnykh, S.V., Flora of the Kungurian Stage of the Middle Cis-Urals and Its Correlation with the Central Angaraland Floras, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 5, pp. 53–62.

Novikov, V.P., Suprychev, V.V., and Khramov, A.N., Correlation of Upper Permian Deposits of the Pamirs and Peri-Urals by Paleomagnetic and Lithological Data, *Permskaya sistema zemnogo shara* (The Permian of the World), Perm: Ural. Otd. Akad. Nauk SSSR, 1991, p. 62.

Okuneva, T.M. and Zakharov, Yu.D., First Findings of Permian Ammonoids in the Borzya River Basin (Transbaikalia), *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1992, no. 4, pp. 142–144.

Pavlova, E.E., Manankov, I.N., Morozova, I.P., *et al.*, Permian Invertebrates of Southern Mongolia, *Trudy Sovmestnoi Sovetsko–Mongol'skoi paleontologicheskoi ekspeditsii* (Works of Joint USSR–Mongolia Paleontological Expedition), 1991, no. 40.

Pyatakova, M.V., Permian and Early Triassic Conodonts of Transcaucasia and Their Startigraphic Implications, *Cand. Sci. (Geol.) Dissertation*, Moscow: Moscow State Univ., 1983.

Resolution on the Stratigraphic Scale for Permian Deposits of the Tethys, in *Postanovleniya MSK i ego postoyannykh komissii* (Resolutions of the ISC and Its Standing Commissions), 1981, no. 19, p. 15.

Ross, C.A. and Nassichuk, W.W., *Yabeina* and *Waagenoceras* from the Atlin Horst Area, Northwestern British Columbia, *J. Paleontol.*, 1970, vol. 44, no. 4, pp. 779–781.

Ross, C.A. and Ross, J.R.P., Late Paleozoic Sea Levels and Depositional Sequences, *Spec. Publ.-Cushman Found. Foraminiferal Res.*, 1987, vol. 24, pp. 137–149.

Rudenko, V.S., Permian Albaillellaria (Radiolaria) of Primor'e and Their Stratigraphic Implications, *Cand. Sci. (Geol.) Dissertation*, Vladivostok: Far Fast Geol. Inst., Far East Branch, Acad. Sci. USSR, 1991, p. 26.

Ruzhentsev, V.E., The Family Cyclolobidae Zettel, *Dokl. Akad. Nauk SSSR*, 1955, vol. 103, pp. 701–703.

Sadovnikov, G.N. and Orlova, E.F., The Taimyrian as a Terminal Stage of the Continental Permian, *Dokl. Ross. Akad. Nauk, Ser. Geol.*, 1994, vol. 338, no. 5, pp. 658–661.

Sheng, H., Late Lower Permian Ammonoids from Xiukang Formation, Lhaze District, Xizang (Tibet), *Himalayan Geol.*, 1984, vol. 2, pp. 219–243.

Sheng Jin-zhang and Jin Yugan, Correlation of Permian Deposits in China, *Palaeoworld 4*, 1994, vol. 1, pp. 14–113.

Shi, G., The Late Paleozoic Brachiopod Genus *Jakutoproductus* Kashirtsev, 1959 and the *Jakutoproductus verchoyanicus* Zone, Northern Yukon Territory, Canada, *Alcheringa*, 1994, vol. 18, pp. 103–120.

Stepanov, D.L., Golshani, F., and Stöcklin, J., Upper Permian and Permian–Triassic Boundary in North Iran, *Geol. Surv. Iran*, 1969, no. 12, p. 72.

Stratigraficheskii slovar' SSSR. Karbon, Perm (Stratigraphic Glossary of the USSR. The Carboniferous, Permian), Leningrad: Nedra, 1977.

Stratigraficheskie skhemy Urala (dokembrii, paleozoi) (Stratigraphic Schemes of the Urals, Precambrian, Paleozoic), Yekaterinburg: AOOT Ural. Geol.–S'emoch. Exp., 1993.

Tapaz, H., Uppermost Permian and Permo–Triassic Beds in Central Iran, *Am. Assoc. Pet. Geol. Bull.*, 1970, vol. 35, no. 8, pp. 1280–1294.

Termier, H. and Termier, G., Les Ammonoides du Permian (Kubergandian) de Tesak (Afghanistan central), *Ann. Soc. Geol. Nord.*, 1972, vol. 42, pp. 105–115.

The Geologic Developments of the Japanese Islands, Minato, M., Gorani, M., and Hunashashi, M., Eds., Tokyo: Tsukiji Shokan, 1965.

The Iranian–Chinese Research Group. Field Work on the Lopingian Stratigraphy in Iran, *Permophiles,* 1995, no. 27, pp. 5–6.

Ueno, K., Permian Aberrant Fusulinaceans from the Akiyoshi Limestone Group, Southwest Japan, *Sci. Rep. Inst. Geosci. Univ. Tsukuba,* 1992, Sec. B, vol. 13, pp. 1–13.

Wang Zhi-hao, Early Permian Conodonts from the Nanshui Section, Luodian of Guizhou, *Palaeoworld 4,* 1994, vol. 1, pp. 203–224.

Wanner, J., Beiträge zur Paläontologie des Ostindischen Archipels: III. Zur Kenntnis der permischen Ammonoideenfauna von Timor, *Neues Jahrb. Mineral. Geol. Paläontol. Abh.*, 1932, no. 67, pp. 257–278.

Wardlaw, B.R. and Glenister, B.F., Leonardian Conodont Biostratigraphy of the Glass Mountains, West Texas, *Palaeoworld 5,* 1995, vol. 5, pp. 12–16.

Waterhouse, J.B., The Permian Brachiopod Genus *Terrakea* Booker, 1930, *Smithson. Inst. Contrib., Paleobil.,* 1971, no. 3, pp. 347–361.

Zakharov, Yu.D. and Sokarev, A.N., *Biostratigrafiya i paleomagnetizm permi i triasa Evrazii* (Permian and Triassic Biostratigraphy and Paleomagnetism of Eurasia), Moscow: Nauka, 1991.

Zakharov, Yu.D. and Oleinikov, A.D., New Data on the Problem of the Permian–Triassic Boundary in the Far East. Pangea: Global Environments and Resourses, *Cand. Soc. Pet. Geol.*, 1994, no. 17, pp. 845–856.

Zhou Zuren, On the Study of the Boundary Strata Between Guadalupian and Lopingian Series, *Permophiles,* 1994, no. 24, pp. 24–26.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 147–155. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 51–59.
Original Russian Text Copyright © 1997 by Belyi.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Mid-Cretaceous Phytostratigraphy and Paleobotany of Northern Asia

V. F. Belyi

Northeast Complex Research Institute, Far East Branch, Russian Academy of Sciences, Portovaya ul. 16, Magadan, 685000 Russia

Received July 7, 1995

Abstract—The analysis of the general sequence of mid-Cretaceous stratofloras of northeastern Asia, proposed by Samylina, including the age and spatial position of various phytostratigraphic subdivisions, revealed local Chauna and Arkagala floras in the northern part of the Siberian–Canadian Cretaceous paleofloral area in addition to the widely spread super-regional floras. The floras were generated during the great mid-Cretaceous reconstruction of the vegetation kingdom (the replacement of Mesophytic floras with Cenophytic plants) accompanied by a sharp change and differentiation of the physico–geographical environment in northern Asia. The phylogenetic relationship between the Chauna and Arkagala floras was confirmed. It was shown that, during the Cenomanian–Santonian, the Arkagala flora dominated in the volcanic upland of northeastern Asia, whereas nearby, in the Penzhina–Anadyr' coastal plains and islands, new coenoses evolved with Cenophytic conifers and angiosperms dominating.

Key words: *phytostratigraphy, stratoflora, successive series of fossil floras, Buor-Kemyuss, Arman, Grebenka, Chauna, Arkagala, taphoflora, phylogenesis, the mid-Cretaceous, northeastern Asia, paleogeographic settings.*

INTRODUCTION

In 1974, Samylina proposed a scheme of biostratigraphic subdivision of the Cretaceous in the northeastern part of the USSR. She interpreted the conception of stratofloras as "the general taxonomic composition of plants that originated from concurrent deposits, had spread over a limited though extensive area, and had the same geological history and a similar development of the organic world" (Samylina, 1974, p. 7). The scheme was adopted by the 2nd Interdepartmental Regional Stratigraphic Conference devoted to the northeastern part of the USSR (*Resheniya ...*, 1978) and used in geological survey and research activities. It was then improved and developed. It was finalized by 1986–1988 (Samylina, 1986, 1988) (Table 1).

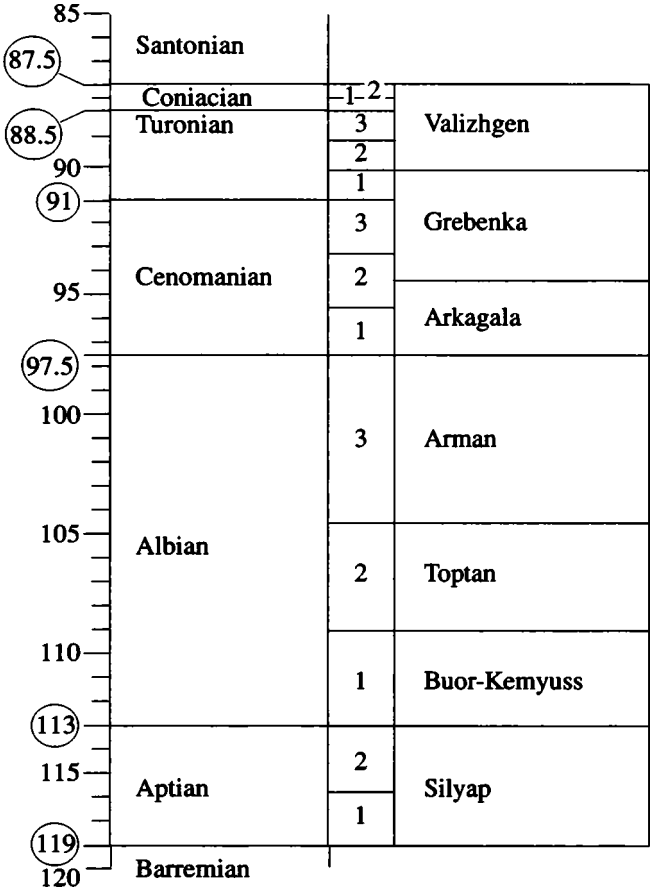
Samylina persistently and quite reasonably emphasized that the elaborated scheme of the mid-Cretaceous phytostratigraphy of the northeastern part of the USSR should not be restricted to regional geological problems, since the Middle Creataceous is the major period in the development of the vegetation kingdom, when the flora of a "pure Mesophytic appearance" was replaced by "typical Cenophytic species." This radical change in flora composition took a short period of time: the middle to late Albian (about 10 m.y.). In that period, vegetation assemblages of a new type actively evolved coexisting with old Mesozoic assemblages. The Mesophytic biocoenoses declined by the beginning of the Late Cretaceous, and Mesophytic relicts, preserved in later floras, did not form independent biocoenoses (Samylina, 1988, p. 111).

Vakhrameev regarded northeastern Asia as a part of the Siberian–Canadian Cretaceous zone of fossil flora (Vakhrameev, 1976). Therefore, Samylina's conclusion that the identified "mid-Cretaceous floras made up successive fossil assemblages," the continuity of which was taxonomically and stratigraphically confirmed, enabled her to suggest, if not to affirm, the presence of this fossil flora sequence over an area extending, at least from the Lena River to Alaska (Samylina, 1988, p. 115).

The taxonomic composition of the Arkagala flora seems to be the most vulnerable point in the conception of a continuous mid-Cretaceous flora succession. Samylina and Lebedev believe that this paleoflora represents a deviation from the successive series due to cooling, which was caused by the intensification of volcanic activity in the region (Samylina, 1974, 1988; Lebedev, 1987). Incidentally, the limited geographical distribution of the Arkagala fossil flora, in particular its lack in the mid-Cretaceous flora sequences of the Vilyui depression and in the Colville depression in Alaska, was almost neglected.

Working on the stratoflora scheme, Samylina noted the peculiar taxonomic composition of the Chauna flora assemblage (Belyi, 1977; Samylina, 1974, 1988), which, most likely, was concurrent with the Arman flora development (Samylina, 1988, pp. 109, 110). However, its place in the fossil flora succession remained uncertain, and the role of the Chauna flora in the development of mid-Cretaceous vegetation in northeastern Asia and Alaska was barely discussed.

Table 1. Mid-Cretaceous floras of the northeastern USSR (according to Samylina, 1976, 1986, 1988)



Note: Age according to Harland *et al.* (1985).

And finally, the two upper floras in the sequence, the Grebenka and Valizhgen, were identified in widely separated localities of the Anadyr'–Koryak geosynclinal system (AKS), whereas other, more ancient floras were discovered in molassic sections of the Verkhoyansk–Chukotka Mesozoic area (VChM) and volcanic accumulations of the Okhotsk–Chukchi volcanic belt (OChVB), where the relative positions of two to four stratofloras were defined by direct observations.

The historical–geological and paleogeographical differences between localities with mid-Cretaceous taphofloras, caused by the intensive structural transformations of that time in the territory of northeastern Asia, were not taken into consideration.

FOSSIL FLORA SUCCESSION AND PALEOGEOGRAPHY OF NORTHEASTERN ASIA IN THE MID-CRETACEOUS

Fossil floras of a wide super-regional distribution are clearly present in the general sequence of mid-Cretaceous stratofloras proposed by Samylina. Among them, there are Buor-Kemyuss, Arman, and Grebenka floras.

The taphofloras, which correspond to the Buor-Kemyuss flora by taxonomic composition and age are widely spread both in northeastern Asia and North America. They are traced in the Verkhoyansk foredeep (Samylina, 1967, 1976), in the western Okhotsk region (Lebedev, 1974), and in Kotel'nyi Island (Vasilevskaya, 1975). In the Colville trough of Alaska, such taphofloras are derived from deposits of the Kukpowruk Formation, the lower part of the Corwin Formation, and from the Tuktu Formation. Smiley united them into "Floral Zone I" of the early–middle Albian age (Samylina, 1976; Smiley, 1969a, 1969b). The Buor-Kemyuss taphoflora corresponds to the "Lower Blairmore flora" in the Alberta and British Columbia provinces of Canada, where their age was dated as early–middle Albian by correlations with marine fauna.

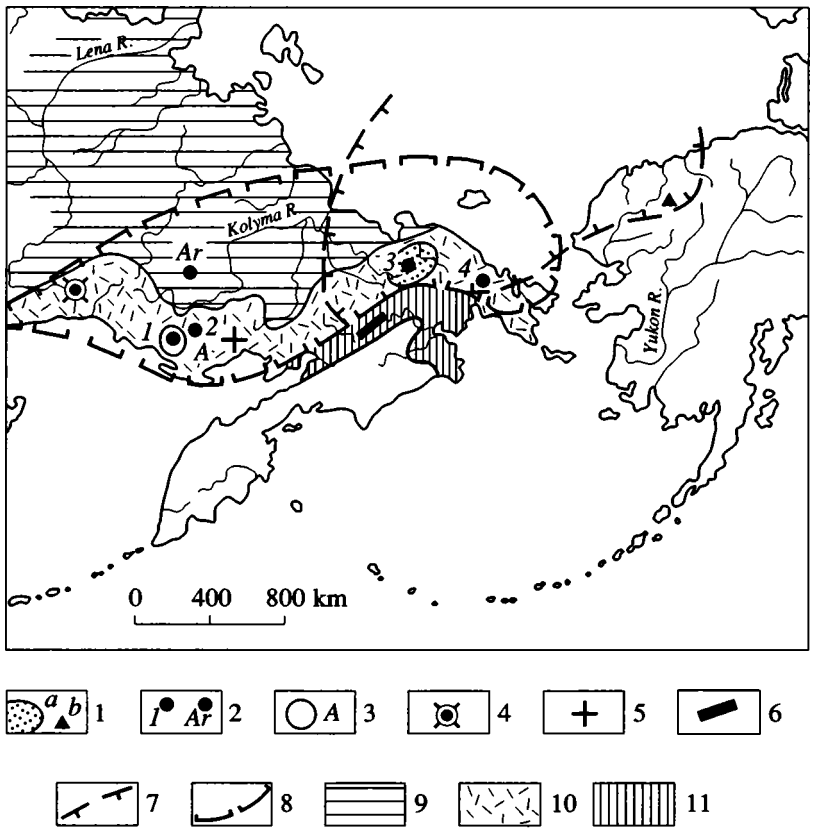
Among the widely distributed Arman-type taphofloras, there are the Agrafen fossil flora of the Vilyui depression (Kirichkova and Samylina, 1978), the "Upper Blairmore flora" of the Alberta and British Columbia provinces (Samylina, 1976; Bell, 1956; Stott, 1968, Vakhrameev, 1974), and assemblages of "Floral Zone III" in the Colville depression (Smiley, 1969b, 1972). Correlations of continental flora with marine fauna served as a basis for referring the "Upper Blairmore flora" to the latest middle–late Albian (Bell, 1956; Stott, 1968), and "Floral Zone III" of the Colville depression to the late Albian (Smiley, 1972).

Similarly, the common taxonomic composition and concurrent marine beds, which contain species of the *Inoceramus dunveganensis ajensis* Zone, suggest that the Grebenka taphoflora from the right bank of the Anadyr' River (Terekhova, 1988; Shchepetov *et al.*, 1992) are correlative with "Floral Zone IV" in the Colville depression (Smiley, 1969a, 1972) and flora of the Dunvegan Formation in western Canada (Bell, 1963; Stott, 1968).

By contrast, the Arkagala flora geographical range is restricted by the OChVB and southeastern VChM (figure): the Arkagala-type taphoflora has not been identified either in deposits of the Vilyui depression (Budantsev, 1968) or in continuous Middle Cretaceous sections of the Colville depression (Smiley, 1969a, 1972).

So, in continuous non-marine sequences of Canada and Alaska containing interbeds with marine fauna, the Arman-type taphofloras give way to Grebenka-type species, whereas in northeastern Asia the distribution patterns are more complicated. Type localities of the Arman and Grebenka taphofloras are widely separated and differ in structure (figure). No Cretaceous marine deposits were found in the Arman taphoflora stratotype locality. In the Anadyr' River Basin, the age of deposits containing Grebenka flora was dated as late Albian–early Turonian according to correlation with marine layers (Terekhova, 1988; Shchepetov *et al.*, 1992).

In the Arman and Ola river basins, deposits containing the Arman taphoflora (Samylina, 1974; Belyi and Samylina, 1987) are overlapped by the Arkagala flora



Distribution of the Chauna and Arkagala taphofloras and major fossil flora elements of northeastern Asia.

(1) Chauna-type taphofloras: (*a*) stratotype taphoflora localities, (*b*) the Chandler River in Alaska; (2) Arkagala-type taphofloras: (*1–4*) main localities of the taphofloras, included in the list of plants in Table 2 (*1*, the Ola Formation, the Ola Plateau; *2*, Mygdykit Formation, Hypothetic Plateau; *3*, the Ergyvaam Formation, the upper left bank of the Mil'guveem River; *4*, the Leurvaam Formation, the Amguema River), *Ar*, Arkagala coal-bearing area; (3) stratotype area of Arman taphofloras; (4) the northern part of the Ulya trough, where Lebedev (1987) identified the Arman–Arkagala–Grebenka taphoflora sequence; (5) Arman–Arkagala mixed taphofloras from the southern Omsukchan region; (6) stratotype area of Grebenka taphoflora; (7, 8) proposed distribution ranges of the Chauna (7) and Arkagala (8) floras; (9–11) paleogeographic zoning of the mid-Cretaceous land: (9) the Verkhoyansk–Kolyma epigeosynclinal region, Verkhoyansk foredeep, and Vilyui depression (accumulative plains, low-mountain topography), (10) the Okhotsk–Chukotka region (marginal–continental volcanic upland), (11) the Penzhina–Anadyr' region (coastal plains and islands).

sequence (the Ola Formation) (Samylina, 1974; Belyi and Samylina, 1987). Lebedev distinguished five (successively replacing each other) floral assemblages (Arinda, Uenmin, Ust'-Amka, Gyrbykan, and Dukchanda), only in the northern part of the Ul'ya trough, where the Arinda assemblage was correlative with the Arman flora, the Gyrbykan with the Arkagala and the Dukchanda with the Grebenka floras (Lebedev, 1987). By their taxonomic composition, the Uenmin and Ust'-Amka assemblages are intermediate between the Arman and Arkagala floras.

Studies on northeastren Asia lead me to conclude that the Arman and Chauna taphofloras do not occur together in a single stratigraphic section or the same stratotype locality. It was established that the Arman taphoflora area within the OChVB does not extend northward and the Chauna taphoflora range does not continue southward beyond 64°N (Belyi, 1994, Fig. 4). Beds with Arman and Chauna taphofloras are usually overlain by acid volcanic rocks, which contain buried plant remains of the Arkagala stratoflora affinity.

Though the Arman and Chauna taphofloras differ notably in taxonomic composition, such plants as *Tchaunia, Brisia ochotica, Phoenicopsis angustifolia* and young conifers *Taxites, Sequoia*, and *Elatocladus* are encountered in both. Taphoflora of "Floral Zone II" in the Colville depression at the Chandler River is analogous to the Chauna floral assemblage (Belyi, 1977, 1994). The flora was recovered in the Lower Killik Tongue containing marine beds with late Albian fauna (Smiley, 1969a, 1972).

The distribution area and age of the Chauna-type taphoflora (figure) suggest that it was a local flora coexisting with the Arman flora and characterized by a wide super-regional distribution.

Thus, two local fossil floras different in age have been identified in the northern Siberian–Canadian

province of Cretaceous paleoflora, namely the Chauna and Arkagala, the distribution ranges of which coincided only in the northern part of the Okhotsk–Chukotka volcanic belt and adjacent northwesten area.

The middle-late Albian "radical change of floras" (Samylina, 1988, p. 111) was of a global rank; it was, at least, recorded throughout the Northern Hemisphere and reflected the general trend of evolution of the vegetation kingdom. In northeastern Asia, this change was concurrent with a great structural landscape transformation. The Buor–Kemyuss taphoflora occurring at the base of the section of OChVB volcanic deposits suggests that a continental marginal volcanic upland began to appear at the boundary between the VChM and AKS (Belyi, 1994). The epigeosynclinal Verkhoyansk–Chukotka Mesozoic lowland was located in the back part of the upland, whereas there was a vast marine basin of the Koryak–Kamchatka geosynclinal area in its frontal part. From the end of the middle to the late Albian, the outer Anadyr'–Koryak zone contiguous to the Okhotsk–Chukotka volcanic upland began to dry up. Coastal plains appeared at the foothills of the volcanic upland, as did vast islands, which were repeatedly flooded.

Therefore, the late Albian land in northeastern Asia consisted of three distinct paleogeographic regions: (1) Verkhoyansk–Kolyma (VKR), represented by intracontinental hills and lowlands, (2) Okhotsk–Chukotka (OChR), which was a volcanic upland, and (3) Penzhina–Anadyr' (PAR), composed of coastal plains and vast lowland islands. So, in the VKR and in the major part of the OChR, the continental stage of development started in the Late Jurassic, and the Mesophytic flora evolved in a rather stable environment, whereas in the PAR land, the development of new vegetation started only in the late Albian. The last region was colonized from both the OChR and an extensive area of central Alaska and its coastal plains. Young progressive conifer species and angiosperms were domonant among colonizers. It is to be noted that the earliest mid-Cretaceous fossil floras of the PAR did not include (or at most occasionally) such Mesophytic relicts as *Sphenobaiera, Pseudotorellia, Phoenicopsis*, and *Czekanowskia*, which were abundant in taphofloras of the VKR and OChR till the early Senonian inclusive.

The tectonic heterogeneity and instability of the PAR during the Middle Cretaceous are reflected in specific features of stratigraphic sections in certain localities. As reported by Paraketsov *et al.* (1974), German (1993), the continental sedimentation and vegetation periods were here episodic in contrast to long-term periods of shallow marine sedimentation. This interfered with the evolution of vegetation and enhanced the role of emigrant forms and assemblages. The Penzhina–Anadyr' sections usually consist of well-dated (by correlation with marine beds) continental sediments containing taphoflora. However, we can not use them to determine the real time intervals of vegetation assemblage evolution.

The new PAR floras, being more mobile and progressive, spread to the adjacent Okhotsk–Chukchi area; vegetation migrated back though with a substantially new taxonomic composition. Such examples are known in some localities of the Okhotsk–Chukchi volcanic belt (Belyi, 1994).

PHYLOGENY OF THE ARKAGALA FLORA

The taxonomic composition and the character of thanatocoenoses of the Arman and Arkagala stratofloras, studied in detail by Samylina, indicate considerable differences between them. In thanatocoenoses of the Arman stratoflora, Mesophytic and Cenophytic plants are usually unmixed. Therefore, "the Mesophytic and Cenophytic types of plant coenoses coexisted, evidently occupying different ecological recesses..." and "successively replaced each other" (Samylina, 1988, p. 102). In the Arkagala stratoflora, Mesophytic relicts "did not form isolated coenoses and were integral parts of the Cenophytic coenoses... Some of them (*Phoenicopsis*) were among the dominants of lowland forests" (Samylina, 1988, p. 102).

The Arkagala stratoflora differs from the Arman assemblage "primarily by the dominating role of Late Cretaceous plants and conifers in its composition" (Samylina, 1988). However, angiosperms make up 21% in the Arkagala flora composition as opposed to 33% in the Arman stratoflora. "Angiosperms are common, in some cases abundant, in thanatocoenoses of the Cenophytic type of the Arman stratoflora. In thanatocoenoses of the Arkagala stratoflora,... angiosperms, with the exception of *Quereuxia* remains, are scarce. Contrary to the Arman angiosperms, Arkagala species are dominated by small-leaved forms, plane tree *Menispermites* disappear..." (Samylina, 1988, p. 102). In the northern part of the Ul'ya trough (Lebedev, 1987) and in the Omsukchan district (Shchepetov, 1991a), the discovered taphofloras, according to their stratigraphic position, taxonomic composition, and thanatocoenoses, occupy an intermediate position between the Arman and Arkagala stratofloras. However, the decline of the angiosperm group in the Arkagala stratoflora should have been explained, and so a hypothesis about strong climate cooling, as a result of intensified volcanic activity, was put forward (Samylina, 1974, 1988; Lebedev, 1987). Incidentally, Arkagala flora was assumed to have existed for a short-term period—the early Cenomanian. This explanation was erroneous. Previously, there were certain objections to it (Belyi, 1988), and they were confirmed after receiving palynologic evidence indicating that the upper age boundary of the deposits with Arkagala taphoflora corresponded to the early Senonian (Markevich, 1989; Belyi, 1994).

There will be no need to use external factors to explain the phenomenon of the Arkagala fossil flora if we compare the taxonomic composition of the Chauna flora assemblage with the Arkagala stratoflora. Table 2

Table 2. List of plants discovered in the Chauna and Arkagala taphofloras from the OChVB sections

Plants	Taphoflora types	
	Chauna	Arkagala
Thallites sp.	+	+
Equisetites sp.	+	+
Osmunda sp.		+
Coniopteris tschuktschorum (Krysht.) Samyl.		+
C. dicksonioides Samyl.	+	
C. aff. *bicrenata* Samyl.	+	
Birisia ochotica Samyl.	+	
Asplenium cf. *dicksonianum* Heer		+
Arctopteris aff. *tschumikaensis* E. Lebedev	+	
Tchaunia tchaunensis Samyl. et Philipp.	+	
Tch. lobifolia Samyl. et Phillipp.	+	
Kolymella raevskii Samyl. et Philipp.	+	
Hausmannia sp.		+
Sphenopteris sp.	+	+
Cladophlebis grandis Samyl.	+	
Cl. tchaunensis Samyl.	+	
Cl. tschuktschorum Philipp.	+	
Cl. frigida (Heer) Sew.	+	
Cl. septentrionalis Holl.		+
Cl. cf. *arctica* (Heer) Sew.		+
Lobifolia sp.		+
Heilungia cf. *iezetujensis* Vachr. et Srebr.	+	
H. cf. *udensis* Koshman	+	
Heilungia sp.	+	
Ctenis paliavamensis Philipp.	+	
C. ex gr. *yokoyamai* Krysht.	+	
Ctenis sp.	+	
Taeniopteris sp.	+	
Sagenopteris cf. *variabilis* (Velen.) Velen.	+	
Ginkgo ex gr. *adiantoides* (Ung.) Heer	+	+
G. ex gr. *lepida* Heer	+	
G. ex gr. *concinna* Heer	+	
G. ex gr. *sibirica* Heer		+
Sphenobaiera cf. *pulchella* (Heer) Fl.	+	
Sph. cf. *longifolia* (Pom.) Fl.	+	
Sph. flabellata Vassil.	+	
Sphenobaiera sp.		+
Phoenicopsis ex gr. *angustifolia* Heer	+	+
Ph. steenstrupii Sew.		+
Podozamites sp.	+	
Araucarites microphylla Sveshn.		+
A. subacutus Philipp.	+	
Athrotaxopsis grandis Font.	+	
Cephalotaxus borealis Samyl.		+
C. aff. *microphylla* Sveshn. et Budants.		+
Taxus cf. *brachyphylla* Samyl.	+	
Torreya gracillima (Holl.) Krysht. et Baik.		+
Taxites ex gr. *intermedius* (Holl.) Samyl.	+	+
T. torreyoides Samyl.		+
Abies sp.		+
Picea sp.		+

Table 2. (Contd.)

Plants	Taphoflora types	
	Chauna	Arkagala
Larix sp.		+
Cedrus sp.		+
Pinus sp.		+
Pityocladus pseudolarixoides Samyl.		+
Pityophyllum ex gr. *nordenskioldii* (Heer) Nath.	+	+
P. ex gr. *staratschinii* (Heer) Nath.		+
Pityospermum minutum Samyl.		+
P. parvulum Samyl.		+
P. piniformis Samyl.		+
P. semiovale Samyl.		+
Pityostrobus sp.		+
Sequoia minuta Sveshn.		+
S. parvifolia Samyl.		+
S. antiqua Samyl.		+
S. cf. *concinna* Heer		+
S. ambigua Heer	+	+
S. cf. *reichenbachii* (Gein) Heer	+	
Sequoiadendron microphyllum Samyl.		+
Metasequoia asiatica Samyl.		+
M. ex gr. *occidentalis* (Newb.) Chaney		+
Metasequoia sp.	+	
Parataxodium neosibiricum Sveshn. et Budants.	+	
Cryptomeria cretacea Samyl.		+
Cunninghamia orientalis (Philipp.) Samyl.		+
Pagiophyllum cf. *triangulare* Pryn.	+	
Taiwania cretacea Samyl.		+
Tollia cf. *cunninghamioides* Sveshn. et Budants.		+
Tollia sp.	+	
Libocedrus catenulata (Bell) Krysht.		+
Thuja cretacea (Heer) Newb.		+
Thuja sp.	+	
Elatocladus zheltovskii Philipp.	+	
E. aff. *acifolia* Bell	+	
E. communis Philipp.		+
Cinnamomoides ievlevii Samyl.	+	
Cinnamomoides sp.		+
Cocculus cf. *extinctus* Velen.		+
Trochodendroides cf. *microphylla* Philipp.	+	
T. ex gr. *arctica* (Heer) Berry		+
Menispermites sp.	+	
Dalbergites sp.		+
Cercidiphyllum minutum Samyl.		+
Ziziphoides sp.	+	+
Cissites cf. *microphyllus* Budants.		+
Macclintockia berinigyana Herman (M. S.)		+
Quereuxia angulata (Newb.) Krysht.	+	+
Dicotylophyllum asimmetricum Samyl.		+
Dicotilophyllum sp.	+	+
Lokyma onkilonica (Krysht.) Samyl.		+
Carpolihtes sp.	+	+

presents the composition of the Chauna flora assemblage based on the collections studied by Samylina or with her participation, and that of the Arkagala taphofloras collected from sections of the Okhotsk–Chukotka region, which were described in her monograph (Samylina, 1988; Fig. 1) and supplemented by specimens presented later by Shchepetov (Table 2).

The origin and phylogenetic relationship of the Chauna assemblage with more ancient floras are not yet clear and can not be discussed, though it should be noted that the relative amount of cycadophytes makes the Chauna assemblage similar to the Pezhenka (Oloi zone) and Buor-Kemyuss (Omsukchan) fossil flora (Samylina, 1974). The abundance of *Tchaunia* ferns in the Chauna assemblage may suggest its compatibility with the Ozhogina (Zyryanka depression) and Ogoner–Yuryakh (Verkhoyansk foredeep) fossil floras (Samylina, 1974; Samylina and Filippova, 1970).

Though the Chauna and Arman floras differ notably in taxonomic composition, the character of their thanatocoenoses is much the same. This may be observed directly in the field in a corresponding locality when collecting plant remains. In the Chauna assemblage, thanatocoenoses of Mesophytic (*Tchaunia, Birisia, Ctenis, Heilungia*) and Cenophytic (*Quereuxia, Metasequoia*) types are commonly isolated, though *Phoenicopsis* ex gr. *angustifolia* is persistent in both (Belyi, 1977; Shchepetov, 1991b).

The comparison of the Chauna and Arkagala floras (Table 2) revealed clear differences between them and certain inheritance. The Arkagala flora is impoverished in ferns and cycadophytes. It does not contain *Tchaunia, Birisia ochotica, Coniopteris bicrenata, Kolymella, Heilungia,* and *Ctenis*, typical representatives of the Mesophytic plants of the Chauna flora assemblage.

Ginkgophytes are also more diverse in the Chauna taphoflora. Species of *Phoenicopsis* ex gr. *angustifolia* are abudant in both taphofloras.

As for conifers, the Chauna and Arkagala taphofloras are dominated by species typical of the Late Cretaceous. Incidentally, conifers are more diverse in the Arkagala taphofloras. Angiosperms are subordinate in abundance, though they are characteristic plant remains of both taphofloras. They are small-leaved and rarely occurring; only *Quereuxia angulata* imprints are rather abundant. Angiosperms are more diversified in the Arkagala than in the Chauna taphoflora, though the relative abundance of *Quereuxia* and *Trocodendroides*, which are most frequently encountered, is approximately the same.

Concluding the comparative description of the Chauna and Arkagala floras, I would like to emphasize again that the Arkagala flora is taxonomically represented here only by taphofloras from sections of the Okhotsk–Chukotka region. And this is not incidental, as taphofloras from coal-bearing deposits of the Arkagala Formation were formed in a different physico–geographical environment (marshland of the Verkhoyansk–Kolyma region), and are rich in diverse angiosperm remains. At the same time, the entire list of the Arkagala flora (Samylina, 1988) includes 23 angiosperm leaf species, but there are only 11 comparable forms in taphofloras from the Okhotsk–Chukotka region. Thus, the taxonomic composition of the Arkagala-type taphofloras from the Okhotsk–Chukotka region considerably deviates from the general tendency of the fossil flora evolution in northeastern Asia, which was suggested by the theory of a single successive development of fossil floras. As inferred from the foregoing discussion, the problem of the Arkagala flora phylogeny can be easily settled if we assume that during the evolution this flora was directly associated with the Chauna flora.

Palynological data indicate that the upper age limit of the Arkagala flora is the early Senonian. The presence of buried plant remains of mixed Arkagala-Arman appearance in certain places of the Okhotsk–Chukotka region and Lebedev's suggestion that the Gyrbykan (Arkagala) flora assemblage is overlain by sediments with Dukchanda (Grebenka) flora (Lebedev, 1987) made it impossible to change the adopted concept of Arkagala flora generation in the early Cenomanian. Thus the development interval of the Arkagala flora ranges from the Cenomanian to the Santonian, i.e., 14.0 m.y. (Harland *et al.*, 1985). This puts forward a specific problem of long-term coexistence and interaction of different fossil floras of northeastern Asia, those from the Okhotsk–Chukotka and Verkhoyansk–Kolyma regions, on the one hand, and from the Penzhina–Anadyr' area, on the other.

CONCLUSION

(1) The substitution of the Mesophytic flora for Cenophytic plant assemblages coincided with great structural and paleogeographic transformations in northeastern Asia, which brought about the formation of three late Albian regions: the Verkhoyansk–Kolyma, Okhotsk–Chukotka, and Penzhina–Anadyr' floral zones. This phenomenon surely affected the development of vegetation.

(2) Northeastern Asia was a part of the Siberian–Canadian paleofloral region. A paleobotanical subregion, which is called after Chauna locality, was separated in the late Albian (possibly at the end of the middle Albian) in the north of this region (north of 64°N) and occupied a relatively small area, extending from the Kolyma River in the west to the Colville River in the east. Taphofloras of the Chauna subregion formed the Chauna floral assemblage, the age of which was dated as the late Albian.

The origin and phylogeny of the Chauna assemblage are not clear. This might have been a result of still uncomprehensible processes, that regulated the formation of the Late Cretaceous North Pacific refugium distinguished by Vakhrameev (1981).

(3) The Arkagala flora is phylogenetically related to the Chauna assemblage. Therefore, it should not be included in the general succession of fossil flora assemblages of northeastern Asia and the Siberian–Canadian province as a whole.

The Arkagala flora originated from the Chauna flora, evidently, in the Cenomanian and existed until the end of the early Senonian (Santonian). Major Arkagala taphoflora localities are confined to volcanic deposits accumulated in the late stage of the OChVB development. The Arkagala flora spread over the VKR, where its taxonomic diversity in coal-bearing areas became wider (especially in the angiosperm group), but did not undergo any essential alterations. The Arkagala flora range was similar to the Chauna flora distribution area, though the former was slightly displaced southwestward with respect to the latter.

(4) The newly formed coastal lowlands and the PAR islands were mostly inhabited by young progressive conifers and angiosperms. Mesophytic relicts, characteristic of the OChR and VKR mid-Cretaceous flora, are absent or rare here already in the Albian–Cenomanian deposits.

The PAR apparently was colonized from both the OChR and Alaska. The Grebenka flora in the PAR might be evolutionarily related to the OChR Arman flora (Belyi, 1988). The "roots" of several other taphofloras, identified by German (1993) in this region, might be looked for in Alaska.

(5) The phytostratigraphic subdivision of the lower Upper Cretaceous in the VKR and OChR, on the one hand, and in the PAR, on the other, can not be based on the same scheme.

Reviewer A.B. Herman

REFERENCES

Bell, W.A., Lower Cretaceous Floras of Western Canada, *Mem.–Geol. Surv. Can.*, 1956, no. 285, pp. 1–331.

Bell, W.A., Upper Cretaceous Floras of the Dunvegan, Bad Heard and Milk River Formations of Western Canada, *Bull.–Geol. Surv. Can.*, 1963, no. 94, pp. 1–76.

Belyi, V.F., *Stratigraphiya i struktury Okhotsko–Chukotskogo vulkanogennogo poyasa* (Stratigraphy and Structures of the Okhotsk–Chukotka Volcanic Belt), Moscow: Nauka, 1977.

Belyi, V.F., Vital Problems of Middle Cretaceous Phytostratigraphy in the Northeastern, USSR, *Preprint of Northeast Complex Research Inst, Far East Branch, USSR Acad. Sci.*, Magadan, 1988.

Belyi. V.F., *Geologiya Okhotsko–Chukotskogo vulkanogennogo poyasa* (Geology of the Okhotsk–Chukotka Volcanic Belt), Magadan: Sev. Vostoch. Kompl. Nauch.–Issled. Inst., Dal'nevostoch. Otd., Ross. Akad. Nauk, 1994.

Belyi, V.F. and Samylina, V.A., The Final Stage of the Okhotsk–Chukotka Volcanic Belt Development According to Observations in the Armani, Ola, and Maltan River Basins, *Tikhookean. Geol.*, 1987, no. 5. pp. 76–85.

Budantsev, L.Yu., Late Cretaceous Flora in the Vilyui Depression, *Bot. Zh.*, 1968, vol. 53, no. 1, pp. 3–16.

Harland, W.B., Cox, A.V., Llewellyn, *et al.*, *A Geologic Time Scale,* Cambridge: Cambridge Univ. Press, 1982.

Kirichkova, A.I. and Samylina, V.A., Correlation of Lower Cretaceous Deposits in the Lena Coal-bearing Basin and Northeastern USSR, *Sov. Geol.*, 1978, no. 12, pp. 3–18.

Lebedev, E.L., Albian Flora and Lower Cretaceous Stratigraphy of the Western Okhotsk Region, *Tr. Geol Inst. Akad. Nauk SSSR,* 1974, vol. 254, pp. 1–147

Lebedev, E.L., *Stratigrafiya i vozrast Okhotsko–Chukotskogo vulkanogennogo poyasa* (Stratigraphy and Age of the Okhotsk–Chukotka Volcanic Belt), Moscow: Nauka, 1987.

Markevich, V.S., The Age of the Arkagala Formation, in *Vulkanogennyi mel Dal'nego Vostoka* (Cretaceous Volcanics of the Far East), Vladivostok: Dal'nevost. Otd. Akad. Nauk SSSR, 1989, pp. 93–98.

Paraketsov, K.V., Pokhialainen, V.P., and Terekhova, G.P., Biostratigraphic Subdivisions of Cretaceous Deposits in the Anadyr'–Koryak Region, *Tr. Sev.-Vost. Nauch.-Issed. Inst. (SVKNII),* 1974, vol. 63, pp. 196–227.

Resheniya 2-go Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po dokembriyu i fanerozoyu Severo-vostoka SSSR, Magadan, 1974–1975 (Resolutions of the 2-nd Interdepartmental Regional Stratigraphic Conference on the Precambrian and Phanerozoic of the Northeastern USSR, Magadan, 1974–1975), Magadan: Sev.-Vost. Territor. Geol. Upravlen., 1978.

Samylina, V.A., Mesozoic Flora from the Kolyma River Left Bank. Ginkgoales, Conifers. General Chapters, *Tr. Biol. Inst. Akad. Nauk SSSR, Ser. VIII., Paleobotanika,* 1967, vol. 6, pp. 134–175.

Samylina, V.A., Early Cretaceous Flora of the Northeastern USSR (On the Problem of the Cenophytic Flora Evolution), *XXVII Komarovskie Chteniya* (The XXVII Readings in Honour of Komarov), Leningrad, 1974, p. 56.

Samylina, V.A., *Melovaya flora Omsukchana* (The Omsukchan Cretaceous Flora), Leningrad: Nauka, 1976.

Samylina, V.A., Correlation of Continental Cretaceous Deposits in the Northeastern USSR, *Sov. Geol.*, 1986, no. 6, pp. 43–53.

Samylina, V.A., *Arkagalinskaya stratoflora Severo-Vostoka Azii* (The Arkagala Stratoflora of Northeastern Asia), Leningrad: Nauka, 1988.

Samylina, V.A. and Filippova, G.G., New Cretaceous Ferns from the Northeastern USSR, *Paleontol. Zh.*, 1970, no. 2, pp. 90–97.

Shchepetov, S.V., *Stratigrafiya kontinental'nogo mela yugo-zapadnogo flanga Kolymskogo nagor'ya* (Continental Cretaceous Stratigraphy in the Southwestern Flank of the Kolyma Upland), Magadan: Sev.-Vost. Komplex. Nauch.-Issled. Inst., Dal'nevost. Otd. Akad. Nauk SSSR, 1991a.

Shchepetov, S.V., *Srednemelovaya flora Chaunskoi serii, Tsentral'naya Chukotka* (The Middle Cretaceous Flora of the Chauna Group, Central Chukotka), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., Dal'nevost. Otd. Ross. Akad. Nauk, 1991b.

Shchepetov, S.V., German, A.B., and Belaya, B.V., *Srednemelovaya flora pravoberezh'ya r. Anadyr'* (The Middle Cretaceous Flora of the Anadyr' River Right Bank), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., Dal'nevost. Otd. Akad. Nauk SSSR, 1992.

Smiley, Ch.J., Cretaceous Floras of Chandler–Colville Region, Alaska: Stratigraphy and Preliminary Floristics, *Am. Assoc. Pet. Geol. Bull.*, 1969a, vol. 53, no. 3, pp. 482–502.

Smiley, Ch.J., Floral Zones and Correlation of Cretaceous Kukpowruk and Corwin Formations, Northwestern Alaska, *Am. Assoc. Pet. Geol. Bull.*, 1969b, vol. 53, no. 10, pp. 2079–2093.

Smiley, Ch.J., Applicability of Plant Megafossil Biostratigraphy to Marine–Non-Marine Correlations: An Example from the Cretaceous of Northern Alaska, in *The 24th Int. Geol. Congr., Section 7*, 1972, pp. 413–421.

Stott, D.F., Lower Cretaceous Bullhead and Fort St. John Group between Smoky and Peace Rivers, Rocky Mountain Foothills, Alberta and British Columbia, *Bull. Geol. Surv. Can.*, 1968, no. 152, pp. 1–279.

Terekhova, G.P., The Age of the Krivorechensk Formation and Grebenka Floral Assemblage, in *Stratigrafiya i paleontologiya Severo-Vostoka SSSR* (Stratigraphy and Paleontology of the Northeastern USSR), Magadan: Sev.-Vost. Komplex. Nauch.-Issled. Inst., Akad. Nauk SSSR, 1988, pp. 100–117.

Vakhrameev, V.A., Cretaceous Deposits of the Rocky Mountains Foothills in Canada (Alberta) and Their Comparative Paleofloral Characteristics, in *Problemy geologii i poleznykh iskopaemykh na XXIV sessii Mezhd. Geol. Kongr. (MGK)* (Problems of Geology and Mineral Resources at the XXIV Session of the IGC), Moscow: Nauka, 1974, pp. 152–163.

Vakhrameev, V.A., The Evolution of Cretaceous Floras in the Northern Part of the Pacific Belt, *XXV sessiya MGK: doklady sovetsk. geologov. Paleontologiya. Morskaya geologiya* (The XXV Session of IGC: Papers of Soviet Geologists. Paleontology. Marine Geology), Moscow: Nauka, 1976, pp. 128–137.

Vakhrameev, V.A., The Evolution of Floras in the Middle Part of the Cretaceous and Ancient Angiospermae, *Paleontol. Zh.*, 1981, no. 2, pp. 3–14.

Vasilevskaya, N.D., Early Cretaceous Flora of the Kotel'nyi Island and its Place among Coeval Arctic Floras, in *Mezozoi Severo-Vostoka SSSR, Mezhvedomstvennoe stratigraficheskoe soveshchanie* (The Mesozoic of the Northeastern USSR, Interdepartmental Stratigraph. Conf.), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., 1975, p. 111.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 156–166. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 60–70.
Original Russian Text Copyright © 1997 by Shcherbinina.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Nannoplankton from Paleogene Deposits in Eastern Kamchatka

E. A. Shcherbinina

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received December 28, 1994; in final form, January 31, 1996

Abstract—A detailed study of the Paleogene terrigenous–tuffogenic beds on Kronotskii Peninsula, Govena Peninsula, and in Karaginskii Island and the Komandor Islands has revealed several levels of nannoplankton occurrences, which allowed their correlation with the standard nannoplankton zonation. Therefore, not only was the principle of applicability of the group to the stratigraphy of the region established, but also the age of some of the beds, previously considered to be barren.

Key words: *Paleogene, zonal stratigraphy, nannoplankton, shales, siltstones, tuffs, flyschoid complex.*

INTRODUCTION

In the Far East, the problem of dating beds with complicated dislocations is now rather acute. The solution is fraught with considerable difficulties. First, the sedimentary rocks of this young and tectonically active region were so substantially reworked that the discovery of not only macro- but also microfossils in an unaltered state is an extremely difficult problem. Second, the complicated tectonic structure of the region does not allow reliable space correlation of sedimentary deposits in different structural–facies zones. Third, the location of the region in high latitudes encouraged the development of many specific, often endemic forms of fossils. The determination of stratigraphic distribution of fossils and the correlation of units identified by them with the better studied low-latitude stratigraphic scales is a challenge in itself.

In this situation, the study of plankton and, in particular, nannoplankton can help solve many stratigraphic problems in the region, because nannoplankton facilitates the construction of zonal scales of high stratigraphic resolution owing to its rapid evolution over time, extensive geographic distribution, and flexible climatic confinement of zonal species.

Until quite recently, the basic role in the Paleogene subdivision of northeastern Russia was played by mollusks; their study laid the basis of the regional stratigraphy, although the drawbacks of the group are evident. Recently, an intensive study of microfossils began (planktonic and benthic foraminifers, radiolarians, diatoms), thus allowing the datings of not only endemic mollusk complexes, but also of beds lacking malacofauna remains. The study of plankton foraminifers was of particular importance, because their well-developed Paleogene zonation, unlike that of siliceous microorganisms, allows more precise datings of the enclosing rocks than were previously achieved as well as the correlation of these rocks with sediments in adjacent regions (Serova, 1966; 1969a, 1969b, 1970, 1973; Krasheninnikov *et al.*, 1988; Ben'yamovskii *et al.*, 1992; Volobueva *et al.*, 1994; and others).

Not long ago, the nannoplankton group was considered to be of little value for the Cenozoic stratigraphy of northeastern Russia. In the region, the abundant carbonate rocks that usually contain nannoplankton have experienced such strong diagenetic transformations that the nannofossils, even if they were initially in the rocks, are now completely recrystallized. Probably, this is the reason why none of the specimens of carbonate rocks studied so far have yielded positive results. The terrigenous deposits, which are typical of these sections, also underwent substantial alterations brought about by fluids, which dissolve the carbonate component of the sediments, and by silicification and tectonic effects.

A few years ago, however, in the flyschoid beds on Il'pinskii Peninsula in northeastern Kamchatka, N.G. Muzylev and D.I. Vitukhin found nannoplankton assemblages that, even though greatly impoverished, have designated three stratigraphic levels of nannoplankton occurrences (Gladenkov *et al.*, 1988). The first level corresponds to the upper Paleocene (Thanetian), the second to the lower–middle Eocene interval (Ypresian–Lutetian), the third to the upper middle Eocene (Bartonian). These occurrences are promising for the use of nannoplankton remains for the subdivision of Paleogene rocks in the Far East regions.

The presence of nannoplankton is now established in several sections in eastern Kamchatka and the Bering Sea islands, i.e., on Govena Peninsula, in Karaginskii Island, on Kronotskii Peninsula, Kamchatskii Mys Peninsula, and in Komandor Islands (Fig. 1). In these

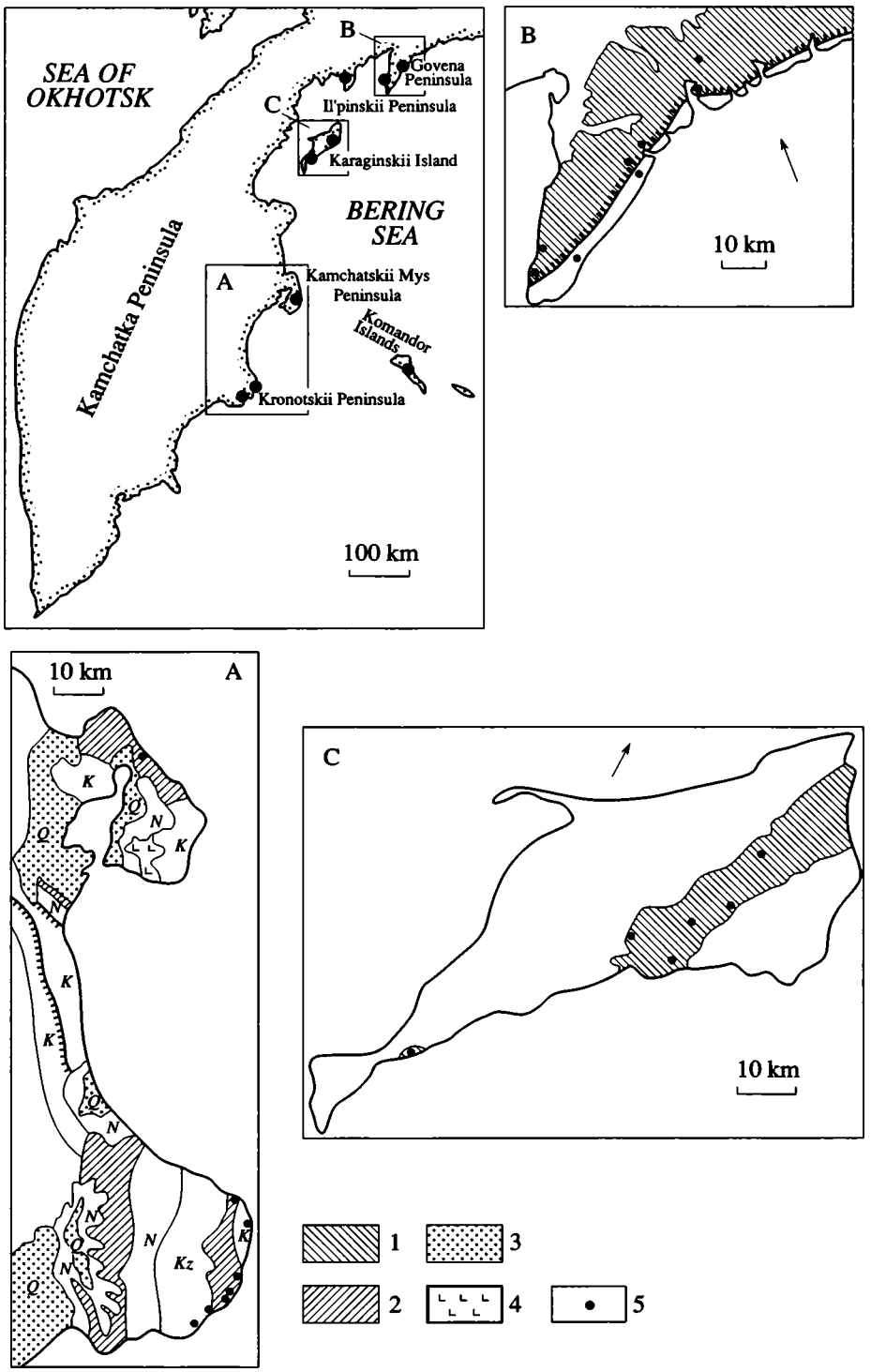


Fig. 1. Localities of the studied Paleogene sections in the Bering Sea region: (1) Flysch beds in the Govena Peninsula and Karaginskii Island; (2) Volcanic–sedimentary beds in the Kronotskii Peninsula and Kamchatskii Mys Peninsula; (3) Quaternary deposits; (4) Magmatic complexes; (5) Studied sections.

localities, the Paleogene deposits are represented mainly by thick terrigenous layers with frequent flows of effusives. Numerous tectonic dislocations, however, distort the normal bedding of the layers and considerably hamper stratigraphic studies and correlation of Paleogene deposits.

In eastern Kamchatka, the nannoplankton specimens were recovered from two types of rocks: volcan-

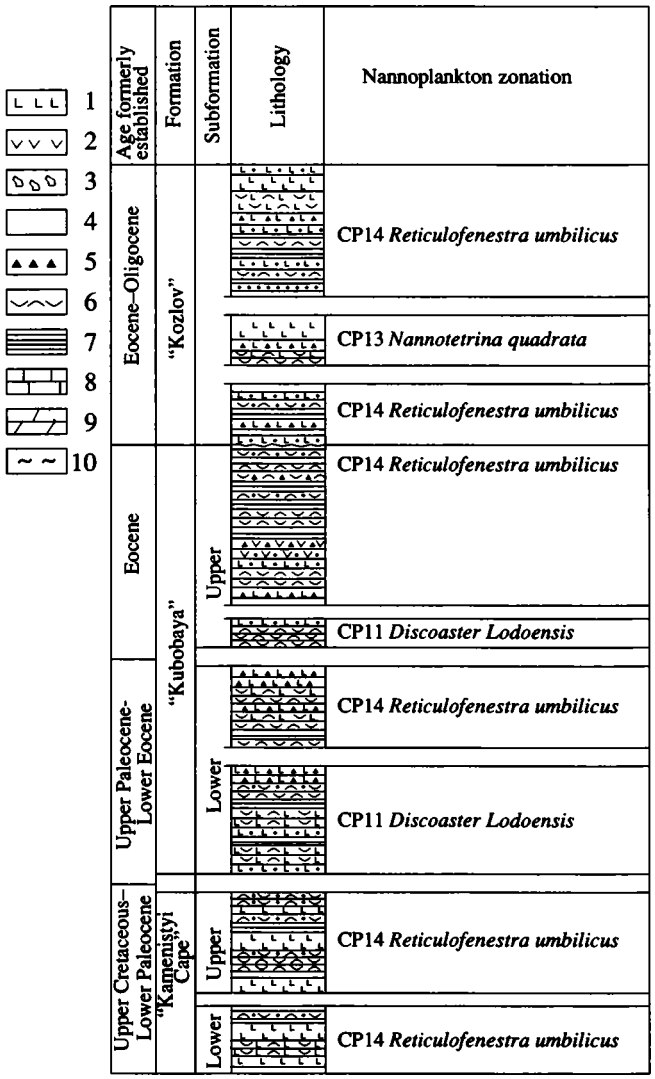


Fig. 2. Composite stratigraphic section of Paleogene deposits in the Kronotskii Peninsula as accepted at present and the age datings by nannoplankton: (1) Basalts; (2) Andesites; (3) Conglomerates; (4) Sandstones, siltstones; (5) Gritstones, breccias; (6) Tuffs; (7) Clays, shales; (8) Limestones; (9) Marls; (10) Opokas.

ogenic–sedimentary layers (Kronotskii Peninsula, Bering Island) and terrigenous–tuffogenic flysch beds (Karaginskii Island, Govena Peninsula, Il'pinskii Peninsula).

Due to adverse facial conditions at all sites, the nannoplankton assemblages are greatly impoverished and moderately or poorly preserved.

KRONOTSKII PENINSULA

The Paleogene deposits of Kronotskii Peninsula are thick volcanogenic–sedimentary rocks in which three formations were distinguished by geological survey: the Kamenistyi Cape Formation, the Kubovaya Formation, and the Kozlov Formation (Fig. 2).

Until now, the Kamenistyi Cape Formation, located in the eastern part of the cape north of Kronotskii Peninsula, was presumably placed at the base of the section, and, in its beds, Cretaceous pollen was discovered. The Kubovaya Formation (there is no apparent contact with the Kamenistyi Cape Formation) is situated in the southeastern part of the peninsula, and M.Ya. Serova has found in it abundant assemblages of early Paleocene plankton and benthic foraminifers of the *Globorotalia angulata* s.l. Zone (Serova, 1966; Krasheninnikov *et al.*, 1988).

The Kozlov Formation, located on the southern brink of Kronotskii Peninsula, overlies with erosion marks the Kubovaya Formation. The study of mollusks date the formation to the late Eocene–Oligocene interval. Nannoplankton is recovered from the deposits of all three formations in different parts of the peninsula. The samples for the study of nannofossils and the descriptions of sections were kindly provided by Yu.B. Gladenkov of the Geological Institute, Russian Academy of Sciences (GIN RAS), and the geological data by M.E. Boyarinova (Kamchatgeologiya Geological Survey). The study of the composition of the nannoplankton assemblages has shown that the age of these formations not only differs from the previous determinations, but the formations themselves include beds of different ages.

The description of the Paleogene deposits on Kronotskii Peninsula is given below in the succession, in which they were assumed to form the sequence "from the base upwards," i.e., from the exposures in the northern part of the peninsula along the Bering Sea coast to the south and further to the west.

The terrigenous–tuffogenic unit south of Kronotskii Peninsula is exposed in the coastal sections between the Vtoroe Ushchel'e and Tret'e Ushchel'e rivers and was earlier attributed to the "Kubovaya" Formation with the following sequence of beds (from base upwards) (Fig. 3).

(1) Conglomerates with dark rounded pebbles of tuffs and hyperbasites (2–3 to 20–30 cm), and also with numerous oyster shells (15 m).

(2) Light gray, almost white opokas with *Variamussium* shells (3 m).

(3) Alternating dark gray tuff sandstones and tuff gravellites (0.5–1 m) with siltstones (0.1–0.3 m) containing *Dentalium* and *Variamussium* shells, sponge spicula, and burrows of detritovores (10 m).

(4) Alternating hard light-colored opokas (0.3 m) and dark sandstones (0.3 m). Total thickness is about 20 m.

(5) Alternating hard light-colored tuff shales that form a ledge among layered softer varieties of the same rock and contain coquina detritus and bryozoan remains (about 20 m).

The nannoplankton in these deposits was discovered in the samples from layer 3 and higher. It composes a

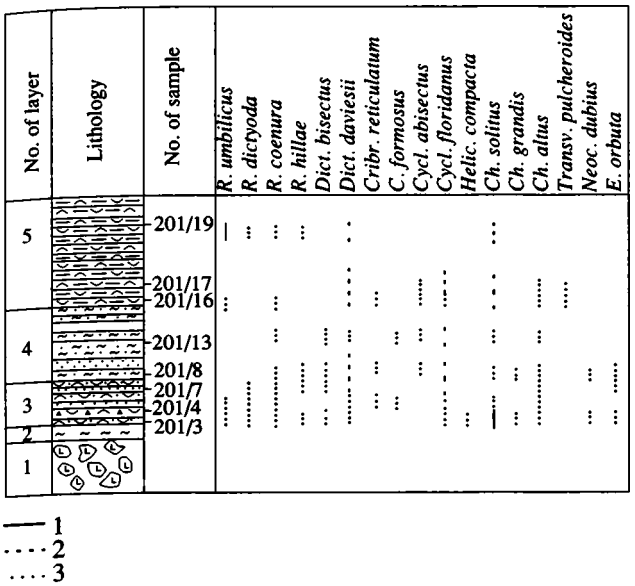


Fig. 3. Scheme of nannoplankton distribution in the "Kubovaya" Formation at the exposure located between the Vtoroe Ushchel'e and Tret'e Ushchel'e rivers (symbols as in Fig. 2): (1) few specimens in every row of the field under microscope; (2) more than 10 specimens in the slide; (3) few specimens in the slide.

rather representative assemblage of the middle Eocene *Reticulofenestra umbilicus,* Zone CP14 which, apart from the index species, includes *Reticulofenestra hillae, R. coenura, R. dutyoda, Cribrocentrum reticulatum, Dictyococcites bisectus, D. daviesii, Chiasmolithus modestus, C. solitus, C. grandis, Helicosphaera compacta, Cyclicargolithus floridanus, Zygrhablithus bijugatus, Neococcolithes dubius, Transversopontis duocavus, T. pulcheroides, Coccolithus formosus, C. pelagicus,* and *Ericsonia obruta.*

A nannoplankton assemblage of the same age was recovered from samples collected in the coastal sequences further south, between the estuaries of the Tret'e Ushchel'e and Bui rivers: *Chiasmolithus altus, C.expansus, C. solitus, Dictyococcites bisectus, Helicosphaera compacta, H.euphratis, Discoaster barbadiensis, Reticulofenestra hillae, R. coenura,* and *Neococcolithes dubius.* These deposits were earlier identified as the Kamenistyi Cape Formation (the lower subformation).

In the estuary of the Kubovaya River, the exposed deposits are referred to the lower subformation of the "Kubovaya" Formation. A flow of agglomerate lavas is overlain (from the base upwards; Fig. 4) by

(1) brown homogeneous tuff gritstone with intricate texture (10–12 m);

(2) layered hard green shale with bleached concretions in the upper part (4 m);

(3) tuffs with large pebbles (10–12 cm) at the base (6 m);

(4) alternating dark-gray tuff gritstone and tuff siltstone (about 30 m);

(5) agglomerate lava (about 8 m);

(6) an alternation of tuff gritstone and laminated siltstone similar to layer 4 (about 30 m).

At the top of layer 6, the nannoplankton assemblage was dated as the late early Eocene (Ypresian); it includes *Discoaster lodoensis, D. barbadiensis, Cruciplacolithus delus, Coccolithus crassus, C. pelagicus, Sphenolithus moriformis, Pontosphaera ocellata, P. plana,* and

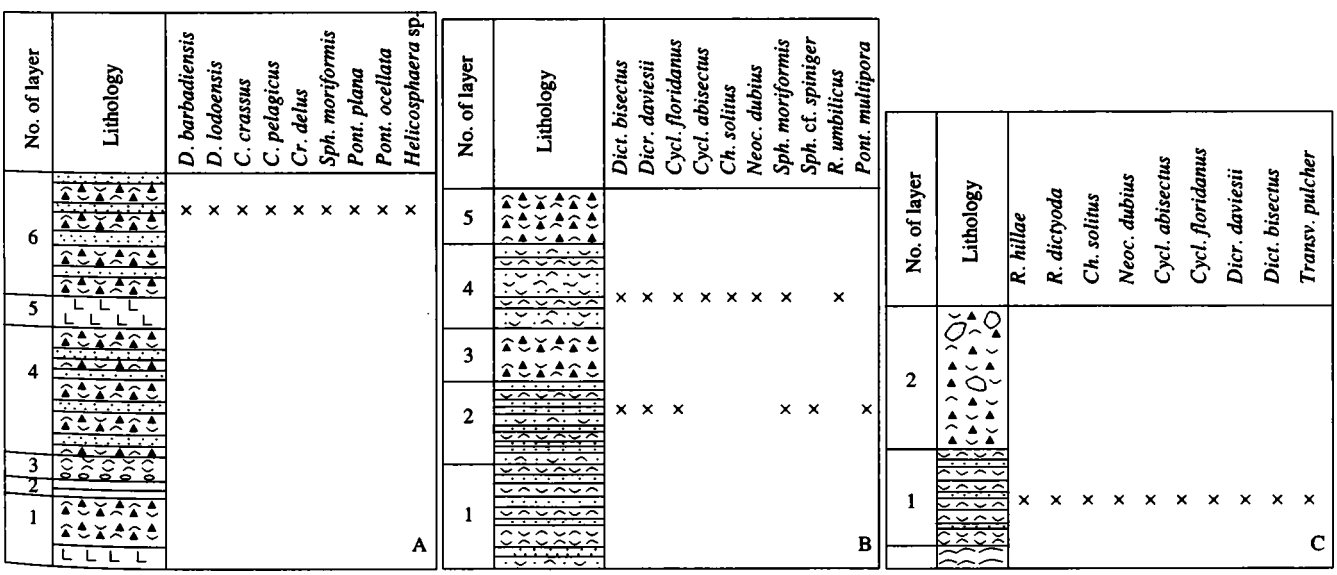


Fig. 4. Scheme of nannoplankton distribution in sections: (A) The Kubovaya River estuary; (B) The Izvilistyi Creek estuary; (C) The Vydrovaya River estuary (symbols as in Fig. 2).

Helicosphaera sp. of the *Discoaster lodoensis* Zone CP11.

South of the Baran'ya River on Cape Ostryi, deposits that were also earlier referred to the "Kubovaya" Formation contain two nannoplankton assemblages of different ages. The rock sequence in the bay north of the cape consists of alternating tuffs, tuff sandstones, tuff gritstones, and tuff siltstones containing a rather poor nannoplankton assemblage, probably of the upper part of the Eocene, bearing *Dictyococcites bisectus, Reticulofenestra umbilicus, Cyclicargolithus floridanus, Sphenolithus* cf. *spiniger, Ericsonia obruta*, and *Chiasmolithus* sp.

South of Cape Ostryi, there is a sequence of exposed green tuffs interbedded by layered bleached tuffs. The sequence contains a nannoplankton assemblage of the *Discoaster lodoensis* Zone CP11 of the upper lower Eocene (Ypresian): *Coccolithus formosus, C. gammation, Helicosphaera seminulum, Sphenolithus radians, Discoaster barbadiensis, D. lodoensis, Pontosphaera ocellata, Transversopontis pulcheroides,* and *Zygrhablithus bijugatus*. In the estuary of Izvilistyi Creek, there is an exposed terrigenous–tuffogenic sequence of the "Kubovaya" Formation (the upper subformation; Fig. 4) containing

(1) a bed of dark gray, if weathered then dark-brown, siltstone with interbeds of blue-gray, and black hard platy siltstone (more than 25 m);

(2) alternating blue-gray finely layered tuff sandstone, greenish-gray silty shale, and bleached thin-platy vitroclastic tuff (about 20 m);

(3) dark massive tuff gritstone with pumice (10–15 m);

(4) a layered reddish bed of tuff sandstone with fine interbeds of tuffite (about 20 m);

(5) massive tuff gritstone with a peculiar "pillow-type" surface of weathering (about 15 m).

Layers 2 and 4 contain the upper middle Eocene (Bartonian) nannoplankton of the *Reticulofenestra umbilicus* Zone CP14: *Dictyococcites bisectus, D. daviesii, Cyclicargolithus floridanus, Chiasmolithus solitus, Neococcolites dubius, Sphenolithus moriformis, S.* cf. *spiniger*, and *Pontosphaera multipora.*

In the lower reaches of the Vydrovaya River, a terrigenous–tuffogenic sequence, previously referred to the "Kozlov" Formation, is exposed (Fig. 4). At the base of the section, pillow basalts are overlain, from the base upwards, by

(1) hard massive dark brown psammitic tuff with interbeds (0.2–0.5 m) of dark gray and black siltstone (about 20 m);

(2) a thick dark gray, brown on the weathered side, tuff gritstone bed with lenses of siltstone (about 30 m).

The siltstone interbed, layer 1, produced a rather ample assemblage of the upper middle Eocene (Bartonian) nannoplankton, of the *Reticulofenestra umbilicus* Zone CP14: *Chiasmolithus solitus, C. grandis, Reticulofenestra hillae, R. dictyoda, Cyclicargolithus floridanus, Coccolithus formosus, Neococcolithes dubius, Dictyococcites daviesii,* and *Transversopontis pulcheroides.*

On the sea coast, west of the Ushchel'e River estuary, there is a thin exposure of rocks referred to the "Kozlov" Formation. The basalts are overlain by beds of tuff sandstones and psammitic tuffs interbedded with black tuff shales and tuff siltstones. The upper part is composed of hard gray bleached tuffs and tuffites with platy partings; the rocks include rather numerous shells of *Variamussium*. The beds are 10 m thick. The composition of the plankton assemblage in these deposits allows their reference to the *Nannotetrina quadrata* Zone CP13 of the middle Eocene (upper Lutetian). There are also *Discoaster binodosus, Chiasmolithus solitus, C. modestus, Reticulofenestra coenura, Nannotetrina quadrata, Cyclicargolithus floridanus, Cruciplacolithus delus, Helicosphaera seminulum, Neococcolithes dubius, Pontosphaera plana, Transversopontis pulcher, Blackites creber,* and *Sphenolithus moriformis.*

Consequently, the stratigraphic correlation between the Kamenistyi Cape, Kubovaya and Kozlov formations assumed earlier is, apparently, incorrect. The oldest rocks of the studied deposits compose the lower part of the "lower subformation of the Kubovaya Formation" (the upper Ypresian, *Discoaster lodoensis* Zone CP11). The age analogues are, obviously, the "Kamenistyi Cape Formation," the upper part of the "lower subformation of the Kubovaya Formation," and its "upper subformation," and the lower part of the "Kozlov Formation" (Fig. 5). These units correspond in age to the Bartonian (*Reticulofenestra umbilicus* Zone CP14). In the upper part of the "Kozlov Formation," a nannoplankton assemblage of the Lutetian is identified (*Nannotetrina quadrata* Zone CP13).

Therefore, the "Kamenistyi Cape," "Kubovaya" and "Kozlov" formations, as indicated earlier, cannot be regarded as valid. They obviously include beds of different ages if apart from the nannoplankton determination we also take into account the earlier datings by foraminifers and pollen. Thus, they do not represent the stratigraphic sequence that was accepted for so many years.

GOVENA PENINSULA

There are two structural zones identified on Govena Peninsula (Chamov, 1991): the northwestern zone of an extensive development of hyperbasite flows in monotonous flysch beds, and the southeastern zone composed of flyschoid beds similar to those in Karaginskii Island; the boundary between them runs along the line of the Primorskii overthrust (Fig. 1B). Chamov (GIN RAS) has collected rock samples on both sides of the thrust zone to infer the age correlation between the rocks of these structures. The presence of nannoplankton is established in both blocks.

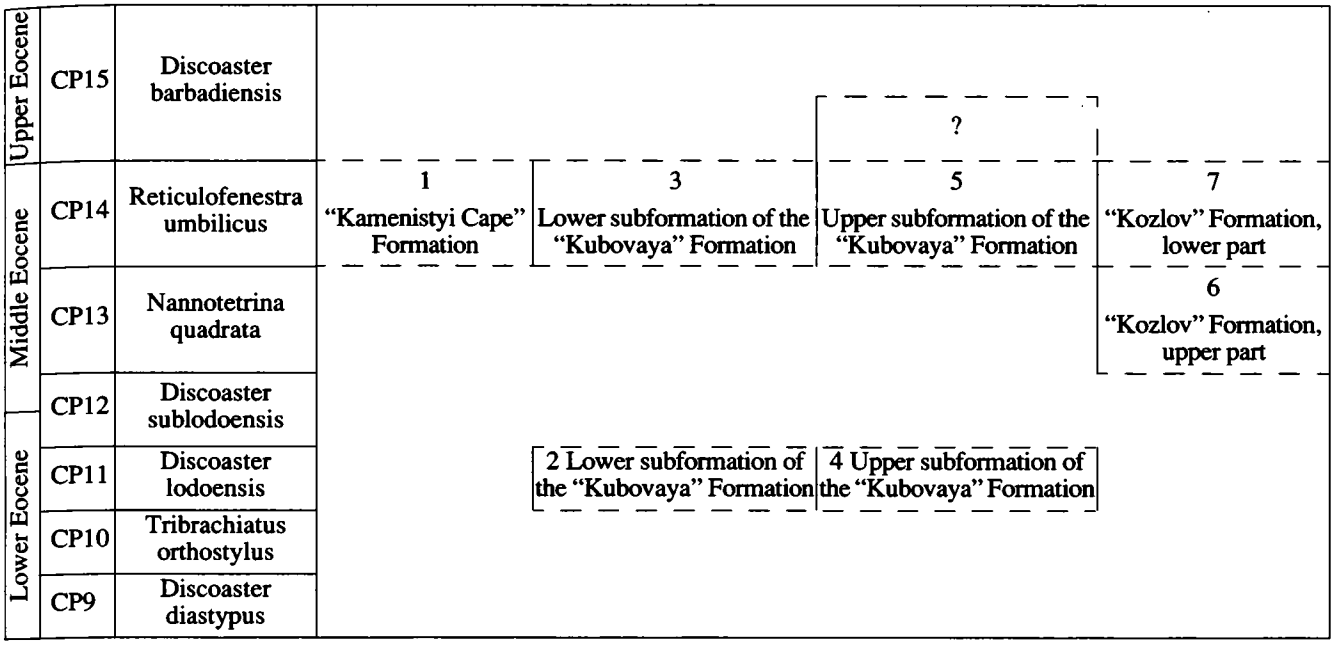


Fig. 5. Stratigraphic correlation of sedimentary formations of the Kronotskii Peninsula based on nannoplankton data: (1) exposure between the Tret'e Ushchel'e and Bui rivers estuaries; (2) the Kubovaya River estuary; (3) exposure between the Vtoroe Ushchel'e and Tret'e Ushchel'e rivers; (4) exposure south of the Cape Ostryi; (5) exposures south of the Baran'ya River and at Izvilistyi Creek estuary; (6) exposure west of the Ushchel'e River; (7) exposure at the Vydrovaya River estuary.

The Paleogene nannoplankton in the northwestern structural–facial zone was discovered in the volcanogenic–sedimentary bed of the flyschoid complex. The macrofauna in these deposits is extremely rare and characteristic of the wide Paleocene–Eocene age interval (Gladenkov, 1972). The plankton foraminifers, recovered from different parts of the peninsula, were identified by Serova. In the northern part of Govena Peninsula (the Pylgovayam River basin), she established the Paleocene foraminiferal assemblage (Serova *et al.*, 1973). At the same site, M.I. Polishchuk identified the late Eocene foraminifers (Kravchenko-Berezhnoi, 1989). In the southwestern part of the peninsula, Serova discovered the foraminifer assemblage of *Globigerina nana–Acarinina primitiva* of the late Paleocene (Serova, 1969a, 1969b) and, presumably, Eocene foraminifers (Serova, 1970).

The rocks of the flyschoid complex are composed of dark gray, almost black shales and siltstones rythmically alternating with greenish-gray tuffs, tuffites, and tuff siltstones; they form a sequence several hundred meters thick. This rock sequence includes numerous basalt flows and is referred to the Il'pinskii Formation.

The most representative are the nannoplankton assemblages in the following localities of the northwestern structural–facial zone:

(1) The Ustavayam River basin, Porog Creek, northeastern part of the peninsula. Nannoplankton is discovered only in one shale sample located 80 m above the lower lava flow. The assemblage includes *Dictyococcites bisectus, Coccolithus formosus, C. pelagicus, Cyclicargolithus floridanus, Reticulofenestra umbilicus, R. coenura, Sphenolithus moriformis*, and *Discoaster deflandrei*. This nannoplankton is composed of species of a rather wide stratigraphic range, which indicate the age of the host rocks in the interval from Bartonian (*Reticulofenestra umbilicus* Zone CP14) to the lower Oligocene (*Heliocosphaera reticulata* Zone CP16.)

(2) A very poor assemblage, including *Reticulofenestra umbilicus, Dictyococcites bisectus, Coccolithus formosus, C. pelagicus,* and *Sphenolithus moriformis* of the same age interval (Bartonian–lower Oligocene), is recovered from the exposure near the Euvayam glacier, 140 m from the base of the section.

(3) The most abundant nannoplankton remains were discovered in the sedimentary rocks covering hyperbasites in the southwestern part of the peninsula, in the Atavropel' Mountains. The thickness of the bedrock outcrop is 70–80 m. The assemblage contains species *Reticulofenestra umbilicus, R. hillae, R. coenura, Discoaster nodifer, D. deflandrei, Coccolithus pelagicus, Coccolithus formosus, Cyclicargolithus floridanus, C. abisectus, Dictyococcites bisectus, D. scrippsae, Sphenolithus radians, S. moriformis, Helicosphaera* sp., *Chiasmolithus* sp., and numerous indefinable small reticulofenestrids and forms of the *Dictyococcites* genus. Despite the relative diversity of the assemblage, only *Sphenolithus radians* indicates that the age of deposits is, apparently, restricted to the lower interval

of the *Reticulofenestra umbilicus*, Zone CP14, though the lowermost upper Eocene could also be implied.

Much more impoverished are the nannoplankton assemblages revealed in deposits of the southwestern structural–facial zone. The nannoplankton was recovered here mainly from the coastal sections in the estuaries of the Irvayam and Potakhavayam rivers in the south of the peninsula. It is represented by rare specimens of *Dictyococcites bisectus, Discoaster deflandrei, D. saipanensis, D. barbadiensis,* and *Cyclicargolithus floridanus.* Such a composition is typical of the interval of zones CP14–CP15 (Bartonian–Priabonian).

The nannoplankton specimens of Govena Peninsula, therefore, suggest, if not a complete synchronism of beds composing both structural–facial zones (this cannot be stated for such a wide time interval, i.e., the upper middle Eocene–upper Eocene), then at least their position within this age interval.

KARAGINSKII ISLAND

In Karaginskii Island, the Paleogene nannoplankton was discovered in two beds of different facies, i.e., in the flyschoid deposits overlying basalts in the central part of the island (similar to the deposits described on the Govena Peninsula), and in the Tons Cape Formation at its southwestern tip (Fig. 1e).

The flysch deposits in Karaginskii Island are represented by alternating sandstones and silty shales with admixtures of tuff material and lava flows at the base. The samples for nannoplankton studies were collected by Chamov (GIN RAS).

The most diverse nannoplankton assemblage was recovered in the lower reaches of the Kulutuvayam River from the flyschoid member of alternating siltstones and shales (the latter prevailing), which enclose pillow-basalt interbeds. The total thickness of the member is about 100 m and the assemblage includes *Reticulofenestra umbilicus, R. hillae, R. coenura, Dictyococcites bisectus, D. scrippsae, D. daviesii, Sphenolithus moriformis, Cyclicargolithus floridanus, Discoaster deflandrei, Coccolithus formosus, C. pelagicus,* and *Isthmolithus recurvus*. The assemblage with this composition dates the enclosing rocks as corresponding to the upper Eocene–lower Oligocene or the *Discoaster barbadiensis* (CP15)–*Helicosphaera reticulata* (CP16) interval.

A less diverse assemblage of the same Eocene–Oligocene boundary interval is established in the sandy siltstone beds exposed in the middle and upper reaches of the Yaklegrivayam River and on the northwestern slope of the Pai Mountain. It consists of *Dictyococcites bisectus, D.* cf. *daviesii, Reticulofenestra umbilicus, R. coenura, R.* cf. *oamaruensis, Discoaster deflandrei,* and *Cyclicargolithus floridanus.*

The accessory elements of the nannoplankton appear only in the samples from the upper reaches of the Kakukvayam River (*Discoaster saipanensis*) and the middle reaches of the Yaklegrivayam River (*Cribrocentrum reticulatum*). These specimens restrict the age interval to the late Eocene, and though it is impossible to establish a stratigraphic correlation of nannoplankton-bearing samples from different exposures, it is quite probable that all of them belong to the upper Eocene.

In the southeastern part of Karaginskii Island, Gladenkov has established the Tons Cape Formation, which he dated as the Oligocene in age (Gladenkov, 1972). Later, the age of the formation was redefined as the late Eocene (Gladenkov *et al.*, 1982). It includes two subformations. The lower subformation of alternating black tuffs, tuff shales, and siltstones is about 240 m thick and contains the shell remains of *Acila* sp., *Yoldia* ex gr. *watasei, Variamussium* ex gr. *pillarense,* and *Dentalium* sp.. The upper subformation is composed of dark gray hard siliceous tuffs with carbonate concretions at the base. Serova, who studied the benthic foraminifers of the Tons Cape Formation, attributes it mainly to the upper Eocene, but does not rule out the middle Eocene age of some beds (Serova, 1975; Krasheninnikov *et al.*, 1988).

The samples of the Tons Cape Formation deposits, presented by D.V. Kovalenko (Institute of the Lithosphere, RAS) for nannoplankton studies, were collected from the upper part of the lower subformation near the Okno Cape. The nannofossils include here *Dictyococcites bisectus, D. daviesii, Reticulofenestra umbilicus, R. hillae, Cyclicargolithus floridanus, Discoaster deflandrei, Braarudosphaera bigelowi, Coccolithus formosus, Chiasmolithus solitus,* and *Sphenolithus moriformis,* thus indicating the upper middle Eocene (Bartonian) age of the rocks, the *Reticulofenestra umbilicus* Zone CP14.

KOMANDOR ISLANDS

There are now two adopted stratigraphic scales of Paleogene deposits in the Komandor Islands (Zhegalov, 1964; Shmidt, 1978) with different ranges of the identified formations and obscure spatial and age correlations. In this paper, I am using Zhegalov's scale and the geological data of Tsvetkov *et al.* (1990). According to their evidence, three formations are identified in the Paleogene section of Bering Island (Fig. 6). At the base of the section, there is the terrigenous Tolstogo Cape Formation with Eocene mollusks (Gladenkov, 1984). The overlying Buyanova Formation is composed of tuffs and conglomerates. The two-member Kamenka Formation in the upper part of the section includes a lower unit of alternating opokas, tuff sandstones, siltstones and shales, whereas the upper one consists of diatomites and tuff diatomites. An assemblage of Oligocene diatoms is established in the upper part of the Kamenka Formation (Gladenkov and Shcherbinina, 1991). From the Nikol'skoe Formation partly correlative with the Kamenka Formation, Serova has recovered the upper Eocene–lower Oligocene foraminifers and L.M. Dolmatova identified diatoms of the

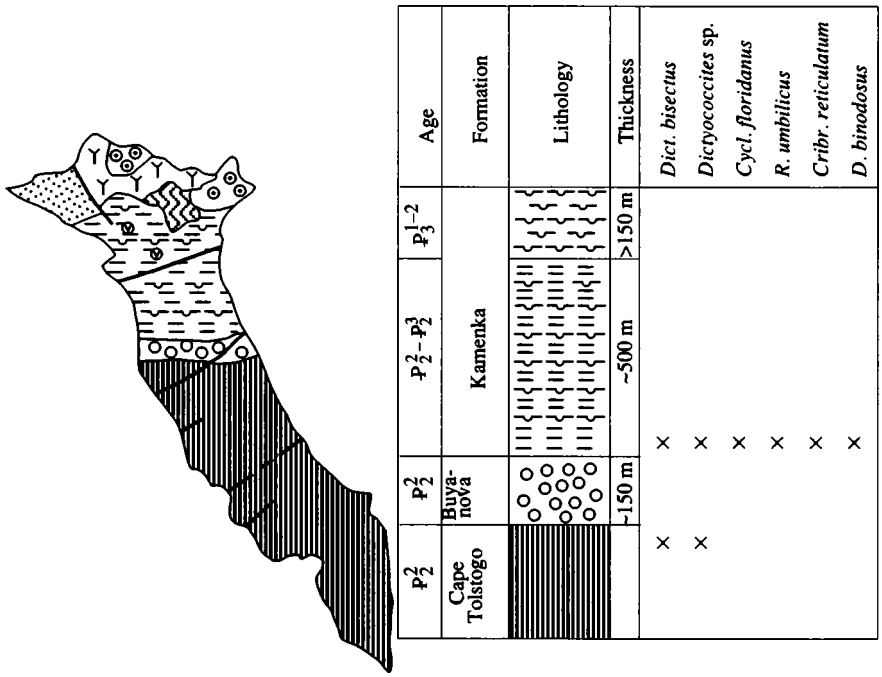


Fig. 6. Levels of nannoplankton occurrences in Paleogene deposits of Bering Island (symbols as in Fig. 2).

lower Miocene and, probably, Oligocene (Shmidt *et al.*, 1973).

Nannoplankton was also discovered in the samples collected from the Kamenka Formation by Gladenkov and from the Tolstogo Cape Formation and Mednyi Island by V.I. Grechin (GIN RAS). The Kamenka Formation yielded nannoplankton only from the base; its assemblage is impoverished and contains single specimens of *Coccolithus pelagicus, Dictyococcites bisectus, Cyclicargolithus floridanus, Reticulofenestra umbilicus, Discoaster binodosus, Cribrocentrum reticulatum,* small reticulofenestrids and species of *Dictyococcites* genus. This assemblage is typical of the upper middle Eocene (Bartonian) and, probably, the lower upper Eocene (Priabonian), i.e., of the interval of the *Reticulofenestra umbilicus* CP14–*Discoaster barbadiensis* CP15 zones.

At the top of the Tolstogo Cape Formation, single finds are represented by *Coccolithus pelagicus, Dictyococcites bisectus,* and small indefinable forms of *Dictyococcites.* The representatives of this genus are known from the Bartonian *Reticulofenestra umbilicus* Zone CP14 and suggest the upper part of the Tolstogo Cape Formation to be no older than the late middle Eocene. Consequently, the overlying deposits of the Kamenka Formation either belong to the top of the designated age interval or are coeval with the Tolstogo Cape Formation. The latter assumption agrees with M.N. Shapiro's viewpoint that the former is thrust over the latter. At present, the data on nannoplankton are insufficient for an unambiguous solution to the problem of the stratigraphic relation between these formations.

The preliminary results of study also showed the presence of nannoplankton in the deposits of the Tolstogo Cape Formation in Mednyi Island. A rather poor assemblage was recovered, containing *Dictyococcites bisectus, Reticulofenestra umbilicus, Cyclicargolithus floridanus, Sphenolithus moriformis, Discoaster nodifer,* and *Helicosphaera* sp. of the same age interval (Bartonian–Priabonian).

KAMCHATSKII MYS PENINSULA

The geological survey revealed three formations in the Paleogene deposits of the Kamchatskii Peninsula Cape: the Vereshchagin (lower Paleocene), the Rifovyi Cape (upper Paleocene), and the Baklan (Eocene). Olenikov (GIN RAS) recovered nannoplankton specimens from the top of the Rifovyi Cape Formation and from the Baklan Formation north of the Soldatskii Bay (Cape Nos). In the Rifovyi Formation, nannoplankton was not detected.

The Baklan Formation is composed of shallow-water rudaceous terrigenic deposits with an admixture of volcanogenic material (Fig. 7). The lower Baklan subformation is represented by tuff conglomerates, psammitic and silty tuffs, siltstones, marls, limestones, and diatomites. These deposits contain Eocene mollusks (Gladenkov, 1972). The upper Baklan subformation includes tuff conglomerates, tuff gritstones, siltstones, andesites, and tuffites with mollusks *Variamussium* ex gr. *kamchaticum.*

The deposits in the lower part of the lower Baklan subformation contain extremely rare nannoplankton

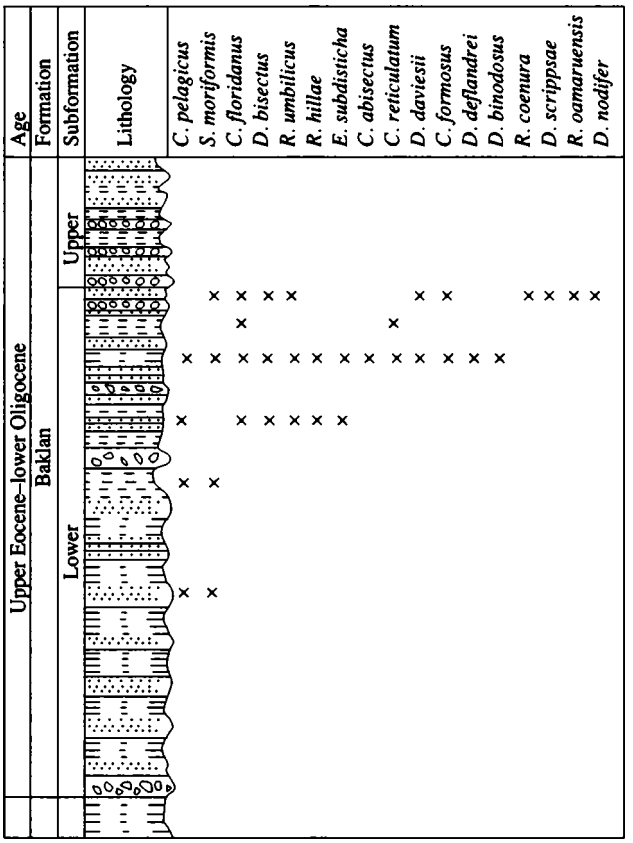


Fig. 7. Scheme of nannoplankton distribution in the Baklan Formation of the Kamchatskii Mys Peninsula (symbols as in Fig. 2).

fossils, mainly single specimens of *Coccolithus pelagicus* and *Sphenolithus moriformis.*

A more ample nannoplankton assemblage was found at the top of the lower Baklan Formation: *Cyclicargolithus floridanus, Coccolithus formosus, C. pelagicus, Discoaster deflandrei, D. nodifer, Dictyococcites bisectus, D. daviesii, D. scrippsae, Reticulofenestra umbilicus,* and *R. coenura.* This assemblage suggests a rather wide stratigraphic range for the upper part of the lower Baklan subformation, i.e., from the top of the middle Eocene (Bartonian) to the base of the Oligocene (zones *Reticulofenestra umbilicus* CP14–*Helicosphaera reticulata* CP16).

CONCLUSION

(1) The study of the Paleogene deposits in Eastern Kamchatka region revealed five nannoplankton assemblages from the following age intervals:

(a) The upper Paleocene (Thanetian), determined by Muzylev and Vitukhin in the Il'pinskii Peninsula;

(b) The upper part of the lower Eocene (upper Ypresian) in the Kronotskii Peninsula;

(c) The lower part of the middle Eocene (Lutetian) in the Kronotskii and Il'pinskii peninsulas;

(d) The upper part of the middle Eocene (Bartonian), in Kronotskii Peninsula, Govena Peninsula, Karaginskii Island, Komandor Islands, Il'pinskii Peninsula, and Kamchatskii Mys Peninsula;

(e) The upper Eocene (Priabonian) in Karaginskii Island and undivided Eocene in Komandor Islands and Kamchatskii Mys Peninsula.

The nannoplankton assemblages of the lower and middle Eocene are sufficiently representative for distinguishing zones of the standard scale by Okada and Bukry (1980). As regards the upper Eocene–lower Oligocene interval, it is almost impossible to determine the Eocene–Oligocene boundary in the region owing to extremely scarce occurrences of species *Discoaster barbadiensis,* and *Discoaster saipanensis,* the disappearance of which marks this boundary. This situation was noted also in the section of deep-sea drilling Site 192A in the boreal region (Shcherbinina, 1992).

(2) On the whole, the general depletion of nannofossil assemblages is, apparently, associated with the adverse conditions for nannoflora development and the accumulation of its remains in the sediments of Far East regions with high tectonic activity. The extensive amount of tuffs in the deposits of the region is evidence of abundant ash suspension in the Paleogene oceanic waters and considerable "dilution" of biogenic components in the sediments. Moreover, significant diagenetic transformations often preclude the investigation of nannoplankton. It is interesting to note that for this purpose the terrigenous deposits (shales and siltstones) are more promising than the carbonate rocks with abundant epigenetic calcite. The studied samples from the limestone interbeds and carbonate concretions were disappointing owing to considerable recrystallization. Evidently, the combination of diagenetic processes of recrystallization and dissolution in terrigenous deposits were more favorable for nannoplankton conservation.

(3) Of all the studied cases only the nannoplankton assemblages from the Kronotskii Peninsula included forms typical of shallow-water shelf deposits (pontosphaerids and helicosphaerids). All other areas of the region yielded assemblages that, though much impoverished, are still typical enough of open marine environments. Mollusks discovered from the "Kubovaya" and "Kozlov" formations likewise testify to sedimentation in the shelf zone (personal communication by V.N. Sinel'nikova). The appearance of nannoplankton in shallow-water environments apparently indicates the transgression maximums. In fact, the nannoplankton levels in Paleogene deposits of the Kronotskii Peninsula coincide with the late Ypresian, late Lutetian and Bartonian transgressions marked on the eustatic curve (Vail *et al.*, 1977) and clearly expressed also in the shallow-water Paleogene deposits of Eastern Europe (Aubry, 1983). The absence of the early Ypresian (zone CP9–CP10) and early Lutetian (zone CP12) nannoplankton coincides with regression periods correlative

with the regional hiatuses in pelagic facies of the Pacific Ocean (Shcherbinina, 1992).

(4) Data on the Paleogene nannoplankton from the Bering Sea region allow us to outline a general climatic trend in this area during the Eocene.

The lower Eocene nannoplankton assemblages from the Kronotskii Peninsula include relatively warm-water organisms, such as discoasters *D. barbadiensis, D. binodosus, D. lodoensis* and sphenoliths *S. radians, S. moriformis.* However, the cold-water chiasmoliths, well represented in the coeval deposits of Site 192A on the Meiji Guyot, are not found on Kronotskii Peninsula, perhaps owing to the general impoverishment of the association.

The upper Lutetian nannoplankton assemblage (*Nannotetrina quadrata* Zone CP13) already shows features of a considerable prevalence of cold-water elements. The only discoaster species *D. binodosus* is found as single specimens, while chiasmoliths (*Chiasmolithus solitus, C. modestus*) and reticulofenestrids (*Reticulofenestra coenura*) are rather abundant.

The Bartonian deposits (*Reticulofenestra umbilicus* Zone CP14) are widespread in the region and include nannoplankton assemblages with abundant and diverse cold-water forms (chiasmoliths, reticulofenestrids, genus *Dictyococcites*), but they almost completely lack warm-water nannoplankton representatives.

The upper Eocene deposits in Karaginskii Island, are also poor in warm-water species, except for a few specimens of discoasters, as it is established in drilling Site 192A.

Therefore, the nannoplankton assemblages of the East Kamchatka region demonstrate a distinct tendency of changing their composition from the rather thermophilic early Eocene to the cold-water late Eocene nannoplankton. On the whole, this scheme is well compatible with the recent idea that, after the early Paleogene temperature optimum, a colder period was triggered by the formation of the circum-Antarctic current in the middle Eocene. The ensuing thermoisolation of Antarctica resulted in a sharply delineated climatic zoning and a considerable cooling in high latitudes. The starting point of this process in the early Oligocene coincides with the disappearance of nannoplankton from the high latitudes of the North Pacific. Therefore, in the boreal region, the potential of this group for the stratigraphy, when the age of deposits is younger than the early Oligocene, is, apparently, not high.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project no. 93-85-68).

Reviewers I.A. Basov, M.Ya. Serova, and Yu.B. Gladenkov

REFERENCES

Aubry, M.-P., Correlations biostratigraphiques entre les formations paleogenes epicontinentales de l'Europe du Nord–Ouest, basees sur la nannoplankton calcaire, *These Universite Pierre et Marie Curie,* Paris, 1983.

Ben'yamovskii, V.N., Fregatova, N.A., Spirina, L.V., *et al.*, Zones of Plankton and Benthic Foraminifera in the Paleogene of Eastern Kamchatka, *Izv. Ross. Akad. Nauk, Ser. Geol.*, 1992, vol. 1, pp. 110–123.

Chamov, N.P., Lithology of Paleogene Volcanogenic Rocks in Govena Peninsula, the Southern Koryak Highland, *Litol. Polezn. Iskop.*, 1991, no. 5, pp. 79–94.

Gladenkov A.Yu., The Cenozoic Stratigraphy in Kamchatka Region by Diatoms Evidence: The Oligocene and Eopleistocene Levels, *Cand. Sci. (Geol.-Min.) Dissertation*, Moscow: Institute of the Lithopshere, Russ. Acad. Sci., 1991.

Gladenkov A.Yu. and Shcherbinina, E.A., First Finds of Nannoplankton in the Paleogene Deposits of the Komandor Islands, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, vol. 1, pp. 126–128.

Gladenkov, Yu.B., *Neogen Kamchatki (voprosy biostratigrafii)* (The Neogene of Kamchatka: Problems of Biostratigraphy), Moscow: Nauka, 1972.

Gladenkov, Yu.B., Molluscan Assemblages Recovered from the Tertiary Deposits of the Komandor Islands, *Dokl. Akad. Nauk SSSR,* 1984, vol. 274, no. 3, pp. 64–82.

Gladenkov, Yu.B., Vitukhin, D.I., and Oreshkina, T.V., Correlation of the Cenozoic in Eastern Kamchatka with the Oceanic Deposits, in *Neogen Tikhookeanskoi oblasti* (The Neogene of the Pacific Region), Moscow: Nauka, 1982, pp. 62–65.

Gladenkov, Yu.B., Muzylev, N.G., Vitukhin, D.I., *et al.*, The Paleogene Nannoplankton of the Koryak Highland, *Dokl. Akad. Nauk SSSR*, 1988, vol. 299, no. 5, pp. 1198–1201.

Kravchenko-Berezhnoi, I.R., The Geological Position of Magmatic Complexes in the Western Framing of the Komandor Basin, *Cand.Sci. (Geol.-Min.) Dissertation*, Moscow: Institute of the Lithosphere, Russ. Acad. Sci., 1989.

Krasheninnikov, V.A., Serova, M.Ya., and Basov, I.A., *Stratigrafiya i planktonnye foraminifery paleogena vysokikh shirot Tikhogo okeana* (The Paleogene Stratigraphy and Plankton Foraminifera in the High Latitudes of the Pacific Ocean), Moscow: Nauka, 1988.

Okada, H. and Bukry, D., Supplementary Modification and Introduction of Code Number to the Low-Latitude Coccolith Biostratigraphic Zonation (Bukry, 1973, 1975), *Micropaleontology,* 1980, vol. 5, no. 3, pp. 321–325.

Serova, M.Ya., *Foraminifery paleotsenovykh otlozhenii Vostochnoi Kamchatki* (Foraminifera in the Paleocene Deposits of Eastern Kamchatka), Moscow: Nauka, 1966.

Serova, M.Ya., Zonation and Correlation of Paleogene Deposits in the Northwestern Part of the Pacific Province, in *Biostratigraphiya, Fauna i flora kainozoya severo-zapadnoi chasti Tikhookeanskogo podvizhnogo poyasa* (Biostratigrapgy, Fauna and Flora of the Cenozoic in the Northwestern Part of the Pacific Mobile Belt), Moscow: Nauka, 1969a, pp. 101–114.

Serova, M.Ya., New Data on the Age of the Volcanogenic–Sedimentary Rocks in the Southeastern Part of the Koryak Highland (Govena Peninsula), *Dokl. Akad. Nauk SSSR,* 1969b, vol. 182, no. 2, pp. 412–415.

Serova, M.Ya., Planktonic Foraminifers in the Upper Paleocene Deposits of the Govena Peninsula, *Vopr. Micropaleontol.*, 1970, no. 12, pp. 168–182.

Serova, M.Ya., Danilesko, L.A., Koleda, A.A., and Petrina, N.M., Subdivision of the Upper Cretaceous and Paleogene Deposits of the Koryak Highland, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1973, no. 10, pp. 73–83.

Serova, M.Ya., Borzunova, G.P., and Shapiro, M.N., The Paleogene of the Southern Part of the Karaginskii Island, Eastern Kamchatka, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1975, no. 11, pp. 73–83.

Shcherbinina, E.A., Stratigraphy and Paleooceanography of the Pacific Ocean in the Paleogene, *Cand. Sci. (Geol.-Min.) Dissertation*, Moscow: Institute of the Lithosphere, Russ. Acad. Sci., 1992.

Shmidt, O.A., *Tektonika Komandorskikh ostrovov i struktura Aleutskoi Gryady* (Tectonics of the Komandor Islands and the Structure of the Aleut Ridge), Moscow: Nauka, 1978.

Shmidt, O.A., Serova, M.Ya., and Dolmatova, L.M., Stratigraphy and Paleontological Description of Volcanogenic Rocks in the Komandor Islands, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1973, no. 11, pp. 77–87.

Tsvetkov, A.A., Fedorchuk, A.V., and Gladenkov, A.Yu., Geological Structure and Magmatism of the Bering Island (Komandor Islands), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1990, no. 7, pp. 40–56.

Vail, P.R., Mitchum, K.M., and Thompson, S., Seismic Stratigraphy and Global Changes of Sea Level, *Seismic Stratigraphy—Application to Hydrocarbon Exploration*, Payton, C.L., Ed., Mem.-Am. Assoc. Petr. Geol., vol. 26, pp. 83–93.

Volobueva, V.I., Gladenkov, Yu.B., Ben'yamovskii, V.N., *et al.*, *Opornyi razrez morskogo paleogena severa Dal'nego Vostoka (p-ov Il'pinskii)* (Reference Section of the Marine Paleogene in the Northern Part of the Far East, the Il'pinskii Peninsula), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., 1994.

Zhegalov, Yu.V., Komandor Islands, in *Geologiya SSSR. Tom 31* (Geology of the USSR. vol. 31), Moscow: Nedra, 1964.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 167–170. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 71–74.
Original Russian Text Copyright © 1997 by Volkova.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Facies Confinement of Paleozoic Acritarchs

N. A. Volkova

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received December 20, 1994; in final form, July 11, 1995

Key words: *acritarchs, Paleozoic, paleoenvironments, facies, paleoecology.*

The facies-controlled distribution of phytoplankton taxa facilitates insight into marine paleoenvironments and provides data important for detailed stratigraphy. The phytoplankton assemblages of poor taxonomic diversity, which usually include sphaeromorphs lacking ornamentation, may occur together with diverse and complicatedly ornamented taxa at the same stratigraphic level. The last taxa demonstrating considerable changes throughout the section are of a high level of importance in stratigraphy, whereas other assemblages with dominant sphaeromorphs can sometimes be encountered in very different intervals of a single section.

Environmental factors, which could be responsible for this contrast in phytoplankton distribution, were considered in many publications. In this paper, I present a brief review of these works in order to elucidate how rock facies control the abundance and diversity of Early and Middle Paleozoic phytoplankton consisting mainly of acritarchs and prasinophytes. This phytoplankton is an object of a model type, because the maximum abundance and diversity of acritarchs was characteristic of the Cambrian–Devonian time, when abundance peaks of prasinophytes representing a conservative group of organisms were caused by particular paleoenvironmental factors.

Many publications suggest that the facies-controlled distribution of Paleozoic phytoplankton is dependent on such factors as paleobasin depth, distance from the shoreline, system of currents, and hydrodynamics. Some researchers also analyzed the influence of taphonomic factors on the composition of microfossil assemblages.

Canadian scientist Staplin (1961), who described the distribution patterns of hystrichosphearids (acritarchs) in Upper Devonian reef facies of the Alberta Province in Canada, was among the first investigators interested in this problem. He distinguished three morphological types of phytoplankton: simple spherical forms, forms with thin processes, and polyhedral forms with thick processes. The first group is widespread; the second is of a similar distribution range, but rarely occurs near the reef; and the third one is confined to the distant reef facies. As Staplin concluded, the quiet deep settings remote from the reef were most favorable for acritarch evolution. All the groups become more abundant away from the reef structure, and such factors as wave activity, organic eradication of microfossils, and diagenetic processes do not influence the phytoplankton distribution. In Staplin's opinion, some deviations from this scheme are caused by sea currents. Similar data on facies control over phytoplankton distribution are known from other sections, such as the Lower Jurassic of Great Britain (Wall, 1965), Silurian of Pennsylvania (Smith and Saunders, 1970), and Ordovician–Lower Silurian of Ohio (Gray and Boucot, 1972). These last authors also noted that acritarch morphotypes are indicators of the water depth. Later publications were devoted to morphological acritarch groupings typical of the Middle–Upper Ordovician marine facies of the United States (Jacobson, 1979) and the Paleozoic Rhadames basin of Libya (Al-Ameri, 1983). Three phytoplankton facies were distinguished in Silurian shelf deposits of England (Dorning, 1981). Main features of palynofacies distribution were also revealed for the Middle Paleozoic as a whole (Richardson, 1984, 1990), and in the Upper Cambrian–Lower Ordovician of China (Yin, 1986).

All cited investigators arrived at the conclusion that the taxonomic compositions of Paleozoic phytoplankton assemblages (acritarchs and prasinophytes) were dependent on paleoenvironments. The low abundance and diversity of phytoplankton with dominant sphaeromorphs was typical of coastal shoals. In the respective deposits, the preservation degree of phytoplankton is usually very poor. In deeper marine settings remote from the shoreline, phytoplankton was more diverse and abundant. Such palynofacies include the better preserved assemblages of complicatedly ornamented forms. Yet further seaward, in epipelagic settings of past oceanic basins, phytoplankton diversity and abundance decreased again. According to the opinion of the cited authors, the water depth, distance from shoreline, and directions of paleocurrents were the main factors responsible for the phytoplankton distribution. Other ecological and taphonomic factors (hydrodynamic environments, type of sedimentation, diagenetic processes, etc.) were considerably less decisive. As for the water depth control, I should note that Gray and Boucot (1972) clearly demonstrated that sphaeromorphic acritarchs inhabited the uppermost water layers, whereas

acanthomorps and other complex forms resided in deeper zones. Accordingly, sphaeromorphs may occur at any distance from the shoreline and are ubiquists. Some acanthomorphic taxa (e.g., genus *Micrhystridium*) display fairly similar distribution patterns; however, near the shore their forms were armored with shorter processes as compared to deep-water species.

Scientists who studied Early Paleozoic acritarchs from the East European platform and northern Eurasia (Rudavskaya, 1974; Piskun *et al.*, 1979; Mens and Pashkyavichene, 1981; Piskun and Zinovenko, 1986) came to analogous conclusions. They also distinguished the water depth and distance from the shoreline as principal factors that controlled the composition of acritarch assemblages. In indicated regions, the most diverse and abundant acritarch assemblages are confined to sediments deposited during the transgression maximum.

In contrast, Colbath (1980) and Welsch (1986) reported on other factors that presumably were responsible for facies confinement of acritarchs. Colbath, who studied monotonous facies of Upper Ordovician deposits in Indiana (United States), detected here an alternation of two phytoplankton assemblages consisting of nine and two species. In his opinion, this alternation independent of rock facies is a result of the rotation of water masses inhabited by different assemblages. At the same time, Colbath did not deny the possibility that this type of distribution could reflect seasonal fluctuations in the diversity of one phytoplankton population.

Welsch (1986), who studied acritarchs from the Middle Cambrian–Ordovician deposits in the Digermul Peninsula of Norway, distinguished six assemblages of microflora. In his opinion, their distribution in rock facies is not a consequence of usually postulated factors, because sphaeromorphs represent an insignificant part of all studied microfloras despite the fact that host sediments have been deposited under conditions of littoral to open marine settings.

The critical assessment of facies control over acritarch distribution was also presented by Moczydlowska and Vidal (1992), who investigated the Lower Cambrian phytoplankton from the Laeså Formation of the Bornholm Island. Different lithologic facies of the formation with distinct acritarch morphotypes correspond to the sedimentary sequence accumulated in a series of settings with littoral to open marine environments. The studied acritarchs of poor to perfect preservation degree represent different morphological subgroups such as Sphaeromorphitae, Acanthomorphitic, Herkomorphitae, Disphaeromorphitae, and Pteromorphitae. Despite different accumulation environments of rock facies, all these subgroups are distributed through the entire sedimentary sequence and are thus independent of facies control. Moczydlowska and Vidal believe that it is impossible to suggest any simple explanation for anomalies in the spatial distribution of fossil phytoplankton, because the physical, chemical, and biological factors that influence the life activity of marine microorganisms are very complex. In present seas, the distribution of phytoplankton populations is dependent on a combination of many parameters such as intensity of illumination, temperature, salinity, depth, layering and hydrodynamics of particular water bodies, and also on oxygen and nutrient contents in sea water. Accordingly, Moczydlowska and Vidal conclude that any attempt to decipher paleoenvironments of microbiota formation meets the invincible difficulties.

In the next publication (Moczydlowska *et al.*, 1993), these authors together with Rudavskaya stressed another aspect of the problem. They reported that anomalies of phytoplankton distribution in present seas cannot be applied to fossil assemblages of microorganisms. The irregular distribution of these assemblages, which is recorded in geological sections, may reflect, as they believe, only a generalized ecological trend of fossil phytoplankton evolution during the given interval of geological time. Nevertheless, many recent works confirm the importance of facies control over the phytoplankton distribution. For instance, Richardson and Rasul (1990) described the shelf and pelagic palynofacies from Upper Silurian deposits of Great Britain. According to their data, sphaeromorphs, tasmanites, and *Micrhystridium* forms with short processes are dominant in littoral sediments, whereas the more diverse acritarch assemblages of acanthomorphs, polygonomorphs, and netromorphs are typical of hemipelagic deposits, and prasinophytes are abundant in deep-sea sediments. Similar distribution patterns are also characteristic of Paleozoic carbonate deposits (Martin, 1993). The facies control over Middle–Upper Cambrian acritarchs is also recorded in the Rhadames basin of western Libya and southern Tunisia (Albani *et al.*, 1991). In the opinion of Martin (1992), the low diversity of the Late Cambrian–Early Ordovician acritarchs in the Alberta Province of Canada is apparently related to the shallow-sea sedimentation environments at that time. In addition, Vidal and Peel (1993) reported on abundant and diverse acritarchs recovered from the Lower Cambrian deep-sea shales of northern Greenland, and on the lower abundance of these microfossils in associated shallow-sea sediments. It is essential that the first group of sediments includes here unusually large (up to 180 μm) acanthomorphic acritarchs discovered for the first time.

Thus, data of many researchers support the idea of facies control over the distribution of Paleozoic acritarchs. The acritarchs are most abundant and diverse in sediments deposited in shelf areas most remote from the shoreline. In sediments accumulated in shallow areas near the coast, the acritarch diversity decreases, and sphaeromorphs become dominant in the phytoplankton composition. Sphaeromorphs are also typical of deep-sea deposits.

These principal features of phytoplankton distribution are not universal. Some aforementioned data (Col-

bath, 1980; Welsch, 1986; Moczydlowska and Vidal, 1992), which are inconsistent with the general distribution scheme, presumably imply the influence of other factors, such as the rotation of water masses, seasonal fluctuations in phytoplankton composition, influence of sea currents responsible for the migration of ornamented forms into coastal shelf zones, selective preservation of different acritarch morphotypes in sediments, and others. However, it is difficult to understand why acritarch assemblages with dominant sphaeromorphs occur at different stratigraphic levels if we discard the ecological factor. Levels with sphaeromorphs that may imply the Precambrian age of host deposits are known in the Upper Devonian Kotlin Formation of the East European platform (Volkova *et al.*, 1979), in the terminal Proterozoic Rodda Beds of southern Australia (Jenkins *et al.*, 1992), in the Middle–Upper Cambrian deposits of the Rhadames basin of western Libya and southern Tunisia (Albani *et al.*, 1991), in the Tremadocian sections of Estonia (Heinsalu *et al.*, 1991) and Alberta Province in Canada (Martin, 1992), in Ordovician sediments of Antarctica (Ribecai, 1991), and in other Paleozoic localities. In some regions, assemblages with dominant sphaeromorphs are actually indicators of Precambrian deposits; however their presence at higher stratigraphic levels, where typical forms are usually ornamented, can be related to specific paleoenvironments. Thus the foregoing discussion provides a sufficient basis to conclude that, in general, the taxonomic composition of Paleozoic phytoplankton is under facies control.

ACKNOWLEDGMENTS

This work is supported by the Russian Foundation for Basic Research, project no. 93-05-9403.

Reviewers A.Yu. Rozanov and M.A. Semikhatov

REFERENCES

Al-Ameri, T.K., Acid-Resistant Microfossils Used in the Determination of Paleozoic Paleoenvironments in Libya, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1993, vol. 44, pp. 103–116.

Albani, R., Massa, D., and Tongiorgi, M., Palynostratigraphy (Acritarchs) of Some Cambrian Beds from the Rhadames (Ghadamis) Basin (Western Libya–Southern Tunisia), *Boll. Soc. Paleontol. Ital.*, 1991, vol. 30, no. 3, pp. 255–280.

Colbath, G.K., Abundance Fluctuations in Upper Ordovician Organic-Walled Microplankton from Indiana, *Micropaleontol.*, 1980, vol. 26, no. 1, pp. 97–102.

Dorning, K.J., Silurian Acritarch Distribution in the Ludlovian Shelf Sea of South Wales and the Welsh Borderland, in *Microfossils from Recent and Fossil Shelf Seas*, Chichester: Ellis Horwood, 1981, pp. 31–36.

Gray, J. and Boucot, A.J., Palynological Evidence Bearing on the Ordovician–Silurian Paraconformity in Ohio, *Bull. Geol. Soc. Am.*, 1972, vol. 83, no. 5, pp. 1299–1313.

Heinsalu, H., Viyra, V., and Paalits, I., Cambrian–Ordovician Boundary Deposits from Saka-II Section, Northeastern Estonia, *Izv. Est. Akad. Nauk*, 1991, vol. 40, no. 1, pp. 30–36.

Jacobson, S.R., Acritarchs as Paleoenvironmental Indicators in Middle and Upper Ordovician Rocks from Kentucky, Ohio and New York, *J. Paleontol.*, 1979, vol. 53, no. 5, pp. 1197–1212.

Jenkins, R.J.F., McKirdy, D.M., Foster, C.B., O'Leary, T., and Pell, S.D., The Record and Stratigraphic Implications of Organic-Walled Microfossils from the Ediacarian (Terminal Proterozoic) of South Australia, *Geol. Mag.*, 1992, vol. 129, no. 4, pp. 401–410.

Martin, F., Uppermost Cambrian and Lower Ordovician Acritarchs and Lower Ordovician Chitinozoans from Wilcox Pass, Alberta, *Bull. Geol. Surv. Can.*, 1992, vol. 420, pp. 1–57.

Martin, F., Acritarchs: A Review, *Biol. Rev. Cambridge Philos. Soc.*, 1993, vol. 68, pp. 475–538.

Mens, K. and Pashkyavichene, L., Facies Control over Acritarch Distribution in the Lontova Horizon of Estonia, *Izv. Eesti NSV Tead. Akad. Toim., Geol.*, 1981, vol. 30, no. 4, pp. 148–155.

Moczydlowska, M. and Vidal, G., Phytoplankton from the Lower Cambrian Laeså Formation on Bornholm, Denmark: Biostratigraphy and Palaeoenvironmental Constraints, *Geol. Mag.*, 1992, vol. 129, no. 1, pp. 17–40.

Moczydlowska, M., Vidal, G., and Rudavskaya, V.A., Neoproterozoic (Vendian) Phytoplankton from the Siberian Platform, Yakutia, *Palaeontology*, 1993, vol. 36, part 3, pp. 1–27.

Piskun, L.V., Zhukov, N.D., and Moiseeva, T.I., Facies and Geochemical Control over Acritarch Distribution Patterns in Silurian Deposits of the Brest Depression, in *Novoe v stratigrafii, tektonike i chetvertichnoi geologii Belorussii* (New Data on Stratigraphy, Tectonics, and Quaternary Geology of Byelorussia), Minsk: Byel. Nauch.-Issled. Geol.-Razved. Inst., 1979, pp. 3–11.

Piskun, L. and Zinovenko, G., Facies Control over Acritarch Distribution Patterns in Lower Cambrian Deposits of Byelorussia, in *Fatsii i stratigrafiya venda i kembriya zapada Vostochno-Evropeiskoi platformy* (Facies and Vendian-Cambrian Stratigraphy in the West of the East European Platform), Tallinn: Akad. Nauk EstSSR, 1986, pp. 120–126.

Ribecai, C., Occurrence of Organic-Walled Microfossils from the Priestley Formation (Wilson Terrane, Northern Victoria Land, Antarctica) and the Problem of their Age: A Preliminary Report, *Mem. Soc. Geol. Ital.*, 1991, no. 46, pp. 157–161.

Richardson, J.S., Palynology, Facies, and Correlation of the Middle Paleozoic, in *Stratigrafiya. Sektsiya C-01. Doklady 27 Mezhdunar. geol. kongr., T. 1* (Stratigraphy. Section C-01. Proc. 27. Intern. Geol. Congr., vol. 1), Moscow: Nauka, 1984, pp. 159–169.

Richardson, J.S. and Rasul, S.M., Palynofacies in a Late Silurian Regressive Sequence in the Welsh Borderland and Wales, *J. Geol. Soc.* (London), 1990, vol. 147, no. 4, pp. 675–686.

Rudavskaya, V.A., Microphytofossil Assemblages as Related to Sedimentation Environments, in *Mikrofotofossilii proterozoya i rannego paleozoya SSSR* (Proterozoic and Early Paleozoic Microphytofossils of the USSR), Leningrad: Nauka, 1984, pp. 159–169.

Smith, N.D. and Saunders, R.S., Paleoenvironments and Their Control of Acritarch Distribution: Silurian East-Central Pennsylvania, *J. Sed. Pet.*, 1970, vol. 40, no. 1, pp. 324–333.

Staplin, F.L., Reef-controlled Distribution of Devonian Microplankton in Alberta, *Palaeontology*, 1961, vol. 4, no. 3, pp. 392–424.

Vidal, G. and Peel, J.S., Acritarchs from the Lower Cambrian Buen Formation in North Greenland, *Rapp.-Grönl. Geol. Unders.*, 1993, no. 164, pp. 1–35.

Volkova, N.A., Kir'yanov, V.V., Piskun, L.V., *et al.*, Vegetative Microfossils, in *Paleontologiya verkhnedokembriiskikh i kembriiskikh otlozhenii Vostochno-Evropeiskoi platformy* (Paleontology of Upper Precambrian and Cambrian Deposits in the East European Platform), Moscow: Nauka, 1979, pp. 4–39.

Wall, D., Microplankton, Pollen and Spores from the Lower Jurassic in Britain, *Micropaleontol.*, 1965, vol. 11, no. 2, pp. 151–190.

Welsch, M., Die Acritarchen der höheren Digermul-Gruppe, Mittel-Kambrium bis Tremadoc, Ost-Finnmark, Nord-Norwegen, *Palaeontographica, Abt. B*, 1986, vol. 201, nos. 1–4, pp. 1–109.

Yin Lei-Ming, Acritarchs, *Aspects of Cambrian–Ordovician Boundary in Dayangcha, China*, Chen Jun-Juan, Ed., Beijing: China Prospect Publishing House, 1986, pp. 314–373.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 171–175. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 75–80.
Original Russian Text Copyright © 1997 by Oleneva.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

BRIEF COMMUNICATIONS

Devonian Stratigraphy of Mongolian Altai

N. V. Oleneva

Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117647 Russia

Received September 14, 1995; in final form, January 23, 1996

Abstract—In the Mongolian Altai, thick and widespread Devonian deposits were initially divided into two large stratigraphic complexes; the lower subdivision spanned the Eifelian Stage, and the upper one corresponded to the summary interval of the Givetian Stage and Upper Devonian. New paleontological materials provided grounds to subdivide these deposits into lower Emsian, upper Emsian–Eifelian, Givetian, Frasnian, and Famennian bed sequences. Data on organic remains from Upper Devonian deposits are presented for the first time.

Key words: *Mongolian Altai, stratigraphic subdivisions, Upper Devonian, brachiopods.*

Previous investigations showed that Devonian deposits of considerable thickness are spread over the entire area of the Mongolian Altai. Preliminary studies on marine invertebrates, such as bryozoans, brachiopods, corals, and crinoids revealed Devonian subdivisions corresponding to considerable intervals of geologic time. For instance, Dergunov *et al.* (1980) distinguished two stratigraphic complexes, the Lower Devonian–Eifelian and the Givetian–Upper Devonian.

In 1988–1991, the Expedition "Sovgeo, MNR," in which I participated, performed a large-scale geological mapping of the Mongolian Altai area. The paleontological materials I collected afford an opportunity to subdivide more accurately the Devonian beds in this region. I studied them mainly in the Sagsai and Baintu basins of the Altai subzone (Fig. 1), which is a part of the Mongolian Altai structural zone (Dergunov *et al.*, 1971; Dergunov and Markova, 1974).

Devonian sediments of the studied region were accumulated in two separated marine basins with different sedimentation environments. This was responsible for their lithologic diversity. Accordingly, Devonian beds in these structures can be correlated only by the biostratigraphic method. The list of studied localities (Fig. 1 and 2) is as follows: Baintu and Altai (Sagsai River, the Altai subzone); Tsagan Nuur, Ulegei, and Delyun (Kobdo River); Khattugiin Gol and Tal Nuur (Delyun–Yustyd depression).

The principal purpose of this work is to describe stratigraphic ranges of fossil fauna and flora, which was collected in a bed-by-bed manner in all localities. I investigated the brachiopod collection, while other groups of fossils were studied by the following experts: L.M. Ulitina (rugose corals) and I.P. Morozova (bryozoans), both at the Paleontological Institute, Russian Academy of Sciences, Moscow; V.F. Kulikova (bivalves), G.A. Stukalina (crinoids), and N.M. Petrosyan (flora), all at the All-Russia Research Institute of Geology, St. Petersburg. In addition, I used data on tabulate and rugose corals from the Geological Foundation materials, which were submitted by N.V. Dubatolov and V.A. Zheltonogova (Siberian Research Institute of Geology, Geophysics, and Mineral Resources, Novosibirsk).

New results provided grounds to distinguish a number of stratigraphic intervals within the Lower Devonian–Eifelian and Givetian–Upper Devonian complexes identified earlier in the Mongolian Altai (see the table).

In the Altai subzone, basal beds of the lower complex discordantly rest on all underlying deposits, including the Silurian rocks. The complex comprises the lower volcano-sedimentary bed sequence (600 m), whose limestone lenses yielded abundant remains of rugose and tabulate corals, and the upper variegated terrigenous deposits (800–1800 m) with basal conglomerates and lenses of pelitomorphic limestones and calcareous siltstones bearing fossil plants. The first bed sequence was studied in two localities of the Altai subzone:

(1) the Sagsai River (right bank), 10 km southeast of the Baintu Somon; here a thick (150 m) limestone lens yielded brachiopod species, such as *Leptagonia* cf. *orientalis* Alekseeva, *Leptostrophia bayrimica* Alekseeva, *Tastaria* sp., *Wilsonella prima* Khalfin, *W. tschernyshevae* O. Erlanger, and *Brachyspirifer* sp.

(2) the Kobdo River middle course (left bank), 16 km away from the Ulegei Somon toward the south-southeast; here the coral assemblage from the 80-m-thick bed of dark gray limestone includes tabulate species *Pachypora tortuosa* Scharkova, *P. tomchumyshensis* Mironova, *Dendropora ganinensis* Mironova, *Egosiella lecomptei* Mironova, *Thamnopora diserta* Mironova, *T. kamyshensis* Mironova, *T. compacta min-*

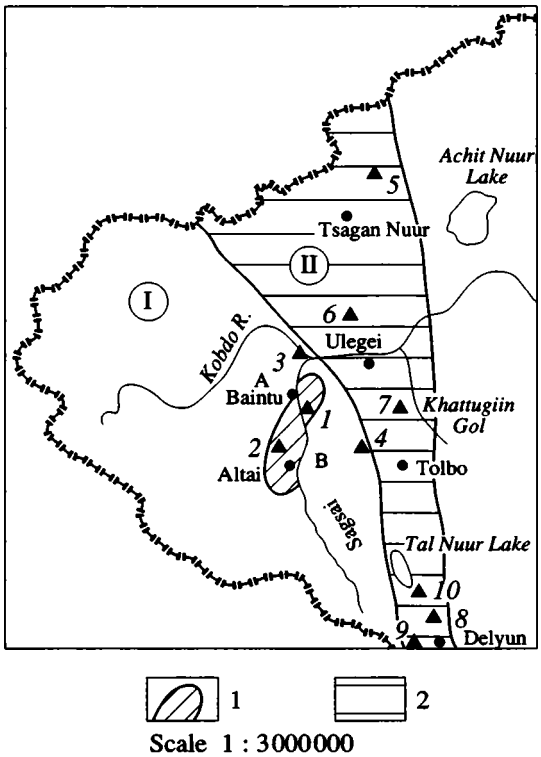


Fig. 1. Geographic scheme of studied localities: I, the Altai subzone with Baintu Somon (*1*), Kholdzatiin Gol Creek (*2*), Kobdo River (*3*), and Tolbo Somon (*4*) localities; II, the Delyun–Yustyd depression with Tsagan Nuur Somon (*5*), Ulegei Somon (*6*), Khattugiin Gol River (*7*), Mt. Bor-Shovgor Uul (*8*), Delyun Somon (*9*), and Tal Nuur Lake (*10*) localities; also indicated are superimposed Buyant (A) and Sagsai (B) basins (1); the Delyun–Yustyd depression is horizontally hachured (2).

ima Scharkova, and *Caliapora elegans* Yanet associated with rugose form *Tryplasma aequabilis* Lonsdale. The composite assemblage from two localities, comprising tabulate specimens *P. tortuosa, T. compacta minima*, and *C. elegans*, brachiopods *W. prima* and *W. tschernyshevae*, and representatives of *Tastaria* group, is typical of the Chulun Horizon of the early Emsian age (Alekseeva, 1990, 1993).

The upper bed sequence of the lower complex was also studied in two localities :

(1) the Kholdzatiin Gol Creek (right tributary of the Sagsai River), left bank northward of the Altai Somon; plant remains of *Caudophyton aquatilis* S. Stp., *Barrandeinopsis beliakovi* Kryshtofovich, *Herbula marinae* S. Stp., *Barsassia ornata* Zalessky, and *Hostimella hostimensis* Potonie et Bernard were recovered here from pelitomorphic limestones.

(2) the Tolbo Somon, three outcrops 20 km northwestward: the identified fossils are tabulate corals *Favosites* ex gr. *goldfussi* Orbigni, *Pachyfavosites* ex gr. *polymorphus* (Goldfuss), *Squameofavosites* ex gr. *obliquespinus* (Tschernyshev), *Caliapora* ex gr. *tenuisquamata* Dubatolov, and *Heliolites* cf. *vulgaris* (Tschernyshev) associated with rugose *Tryplasma* ex gr. *devoniana* Soshkina, *Taimyrophyllum carinatum* Bulvanker, and *Xistriphyllum* ex gr. *uralicum* Soshkina, and also with trilobite *Neoprobolium* ex gr. *altaicum* (Khalfin).

The listed species include Tabulata forms, which are typical of the Tsagankhalga Horizon of Mongolia and also are known from the Shanda and Mamontovo horizons of the Altai-Sayany region and their equivalents (Alekseeva, 1993; Dubatolov, 1982). Floral species *C. aquatilis* and *B. beliakovi* occur in Shanda and Mamontovo horizons of the Salair region, which are equivalents of the Tsagankhalga Horizon of Mongolia. In the opinion of N.M. Petrosyan, Lycopodiaceae remains from deposits in question are similar to *Artschalyphyton unicum* Senk., the zonal index species of the upper Eifelian Besobinka Horizon in Kazakhstan. Thus, the described assemblage of fauna and flora should be attributed to the Tsagankhalga Horizon of Mongolia, which is Emsian–Eifelian in age.

In the Delyun–Yustyd depression, the lower complex is also of a two-member structure. Its lower bed sequence (400–1200 m) is variegated in color and terrigenous–volcanogenic in composition; the upper dark-colored beds (2100 m) are represented by cherty tuffaceous–terrigenous deposits, which conformably overlie lower beds.

In the indicated structure, the lower bed sequence rests on an eroded surface of Lower Paleozoic rocks. For the moment, paleontological remains from the last rocks are unknown.

The upper bed sequence was erroneously considered as Late Devonian in age, however northward of the Delyun Somon, near the Mt. Bor-Shovgor Uul, it yielded older fossils. Among the plant remains, there were *Aneurophyton germanicum* Krausel et Weyland, *Barsasopteris nativa* S. Stp., *Uralia camdjalensis* Petrosian, *Protolepidodendron scharyanum* Krejci, *Barrandeinopsis beliakovi* Kryshtofovich, *Barsassia ornata* Zalessky, and *Herbula marinae* S. Stp., while crinoids were represented by *Salairocrinus humilis* Dubatolova. On the basis of flora comprising *B. ornata, B. nativa*, and *H. marinae* typical of Shanda and Mamontovo horizons of the Salair Range, these deposits can be correlated with the variegated terrigenous sequence of the Altai subzone and, apparently, with the Tsagankhalga Horizon.

The upper complex (Givetian–Frasnian), which was distinguished by Dergunov and Luvsandanzan (1970, 1971) in the Altai subzone, overlies the Cambrian–Ordovician sequence with an angular unconformity. This 800-m-thick complex consists of variegated volcano-sedimentary rocks with limestone interbeds. I referred it to the third bed sequence, whose type section is located near the Baintu Somon, the right bank of the Sagsai River. Brachiopods discovered here are *Euryspirifer pseudocheehiei* (Hou Hun-fe), *Spinocyr-*

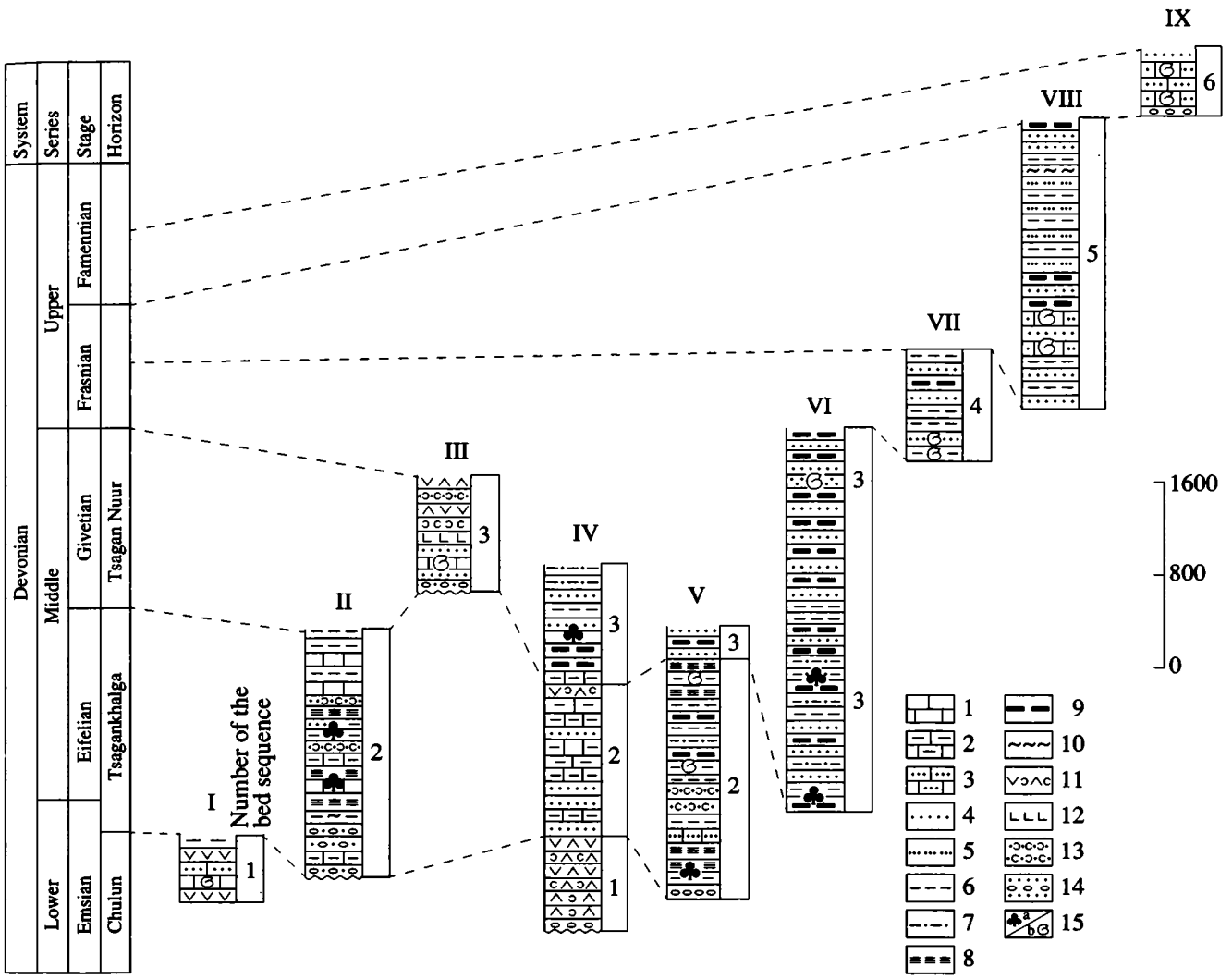


Fig. 2. Correlation scheme for studied Devonian sections of the Mongolian Altai. The Altai subzone: (I) Kobdo River middle course, 16 km south-southwest of the Ulegei Somon; (II) left bank of the Kholdzatiin Gol Creek, 25 km to the south of the Baintu Somon; (III) near the Baintu Somon. The Delyun–Yustyd depression: (IV) northward of the Delyun Somon; (V) near the Mt. Bor-Shovgor Uul; (VI) 2.5 km to the southwest of the Mt. Dund-Tolgoi; (VII) near the Mt. Khuiten-Sarval Uul; (VIII) left wall of the Urt-Zuukh Creek valley, 4.2 km northward of the Tsagan Nuur Somon; (IX) southern shore line of the Tal Nuur Lake. Symbols for lithology: (1) limestone; (2) clayey limestone; (3) sandy limestone; (4) sandstone; (5) fine-grained sandstone; (6) siltstone; (7) silty sandstone; (8) cherty siltstone; (9) "black shale" siltstone; (10) shale; (11) lava, or tuff of acidic to intermediate composition; (12) lava, or tuff of basic composition; (13) tuff, or tuffaceous sandstone; (14) conglomerate; (15) indicated position of floral (a) and faunal (b) remains.

tia martianofi (Stuckenberg), *S. kizylschinica* Gratsianova, *S. carinata* Ehlers and Wright, *S. audacula* (Owen), *Athyris concentrica* (Buch), and *Sibiratrypa* ex gr. *vassinensis* Rzonsnickaja, while Rugosa are represented by *Altaiophyllum belgebaschicum* Ivania. In the Altai–Sayany region, this fauna is typical of *Ciela* Beds (upper Givetian Alchedat Horizon).

In the Delyun–Yustyd depression, the formerly recognized upper complex (Givetian–Upper Devonian) conformably rests on Emsian–Eifelian deposits. It consists of sandy and silty ("black shale") sediments, whose thickness is locally up to 5500 m. My comprehensive study on brachiopods from the Delyun–Yustyd depression provided grounds to discriminate here four stratigraphic intervals, distinct in lithology and bearing organic remains different in age. One of them, the lowest in the section, consists of typical sandy to silty "black shale" deposits, which are over 2600 m in total thickness. According to recovered fauna and flora, this unit corresponds to the Givetian Tsagan Nuur Horizon recognized by Alekseeva (1990).

These deposits (the third bed sequence in my classification) are most widespread in the Delyun–Yustyd depression. I studied them near the Tsagan Nuur and Ulegei somons, and also along the Khattugiin Gol River.

Correlation of Devonian deposits in the Mongolian Altai and adjacent regions

Standard scale			Mongolia	Number of bed sequence	Mongolian Altai		Salair	Kuznetsk basin
					Altai subzone	Delyun–Yustyd depression		
System	Series	Stage	Horizon		Lithology		Horizon	Horizon
Devonian	Upper	Famennian		6		Variegated limestones and sandstones, 250 m		Peshcherki
		Frasnian		5		Gray sandstones, 1800–2100 m		Vassino
				4		Greenish-gray siltstones and sandstones, 800 m		Izyly
	Middle	Givetian	Tsagan Nuur	3	Variegated volcano-sedimentary beds, 800 m	Gray sandstones and siltstones, 2600 m	Alchedat	Biya
		Eifelian	Tsagankhalga	2	Variegated terrigenous sediments, 800–1800 m	Dark-colored tuffaceous-terrigenous beds, 2100 m	Shanda–Mamontovo	
	Lower	Emsian	Chulun	1	Volcano-sedimentary beds, 600 m	Variegated terrigenous–volcanogenic beds, 400–1200 m	Belaya–Salairka	

(1) Sandstone and siltstone beds in the right bank of the Khattugiin Gol River yielded plant remains of *Aneurophyton germanicum* Krausel et Weyland, *Hyenia sphaenophylloides* Nathorst, *Svalbardia polymorpha* Hoeg, *Barrandeina pectinata* Nathorst, *Calamophyton bicephalum* Leclercq et Andrews, and *Thamnocladites vanopdenbaschii* Stockmans. Typical upper Givetian species from this assemblage, such as *S. polymorpha* and *T. vanopdenbaschii*, occur in the middle part of the rock sequence. Its terminal sandstone–siltstone member encloses brachiopods *Euryspirifer pseudocheehiei* (Hou Hun-fe), *Spinocyrtia martianofi* (Stuckenberg), *Sibiratrypa* ex gr. *vassinensis* Rzonsnickaja, and *Dagnachonetes dundensis* Oleneva.

(2) Deposits of the Tsagan Nuur Horizon, which are exposed 15 km southwestward of the Tsagan Nuur Somon, accommodate brachiopods *Schizophoria (Schizophoria) striatula* (Schlotheim), *Leptagonia sinuata* Rzonsnickaja, *Sibiratrypa lebedjanica* (Rzonsnickaja), *Euryspirifer pseudocheechiei* (Hou Hun-fe), *E. pseudocheehiei alatus* (Stuckenberg), *Spinocyrtia martianofi* (Stuckenberg), *S. audacula* (Owen), and *Tsaganella plana* Oleneva, which associate with bryozoans *Hemitrypa* cf. *devonica* Nekhoroshev, and *Semicoscinium* cf. *planiformis* Krasnopeeva, and also with trilobites *Scutellum* ex gr. *costatum* Puschkin.

The fourth and fifth bed sequences, which are respectively composed of greenish-gray sandstone–siltstone association (800 m) and dominant gray sandstone beds (1800–2100 m), yielded Frasnian brachiopods and bivalves. The sixth interval (250 m) spans the limestone–sandstone alternation suggested to be Famennian in age. These rock units are described below.

Upper Devonian (Frasnian and Famennian) deposits with fossil remains were recognized only in the Delyun–Yustyd depression. Here, Frasnian beds conformably overlie rocks of the Tsagan Nuur Horizon (the third bed sequence). The lower stratigraphic interval of the beds (the fourth bed sequence) is an occurrence level of both Givetian and Upper Devonian (Frasnian) fossils, while the upper one (the fifth bed sequence) yielded only Frasnian species.

I studied the fourth bed sequence in three localities: (1) southwest of the Tsagan Nuur Somon in the left wall of the Khar Gov Valley; (2) northward of the pass Shine Davaa; and (3) near the Mt. Khuiten-Sarval Uul located to the north of the Ulegei Somon. The composite fossil assemblage from these localities includes brachiopods *Euryspirifer pseudocheehiei* (Hou Hun-fe), *Mucrospirifer mesocostalis* (Hall), *M. mesocostalis tricostata* (Rzonsnickaja), and *Productella* sp. together with bivalves *Leptodesma* (*Leptodesma*) *spirigerum* (Conrad), *Cypricardella* cf. *gregaria* (Hall et Whitfield), *Sphenotus* cf. *tiogensis* McAlester, *Parallelodon delitescens* (Beushausen), *Paracyclas* cf. *rectangularis*

Sandb., *Ptychopteria (Ptychopteria) proto* Hall, *Nuculoidea* sp., and *Leptodesma* sp. Among listed forms there are species characteristic of Givetian and Frasnian deposits. The assemblage composition resembles that recovered from the Izyly Horizon (lower Frasnian) in the Kuznetsk basin, where it also includes some transit species widespread in Givetian deposits (Rzhonsnitskaya, 1968; *Resheniya ...*, 1982).

The fifth bed sequence (1800–2100 m in thickness) is mainly composed of sandstones widespread to the north of the Tsagan Nuur Somon and studied in the right wall of the Urt-Zuukh creek valley. I discovered here brachiopods *Eoschuchertella chemungensis* (Conrad), *Elytha fimbriata* (Conrad), *Douvillinoides singularis* Oleneva, *Mucrospirifer mesocostalis* (Hall), and *Cyrtospirifer schelonicus* Nalivkin coexisting with bivalves *Prothyris* (?) cf. *lanceolata* Hall, *Vertumnia* cf. *reversa* (Hall), *Pteronites* sp., and *Pterinea* sp. Deposits with these fossils are definitely Frasnian in age, and their interval can be correlated with the Vassino (lower Frasnian) Horizon in the Kuznetsk basin.

I consider Famennian beds of the Delyun–Yustyd depression as a provisionally recognized unit. The variegated limestone–sandstone sequence of a minor tectonic block near the southern shore line of the Tal Nuur Lake yielded brachiopods *Cyrtospirifer tschernyschewi* Khalfin and *C.* aff. *procumbens* Simorin along with bivalves *Nuculoidea peetzi* (Khalfin), *Sanguinolites? contractus* (Hall), and *Eoschizodus? chemungensis* (Conrad). Such forms as *C. tschernyschewi* and *N. peetzi* occurring among these fossils are known from the lower Famennian Peshcherki Horizon in the adjacent Kuznetsk basin (Rzhonsnitskaya, 1968), and this is the only argument to suggest the Famennian age for the bed sequence in question.

CONCLUSION

(1) Devonian deposits in the Mongolian Altai are differentiated for the first time into six bed sequences different in age, as they respectively yielded lower Emsian, upper Emsian–Eifelian, Givetian, Frasnian, and presumably Famennian assemblages of organic remains.

(2) The three lower bed sequences I discriminated correspond to the Chulun, Tsagankhalga, and Tsagan Nuur horizons of the unified stratigraphic scheme of Devonian deposits in Mongolia.

(3) Studied organic remains were used to suggest for the first time that Upper Devonian deposits of the Mongolian Altai comprise bed sequences comparable with the Frasnian Izyly and Vassino horizons, and perhaps with the Famennian Peshcherki Horizon of the Kuznetsk basin.

ACKNOWLEDGMENTS

I am grateful to all aforementioned experts, who studied different groups of organic remains, and also to geologists of the Expedition "Sovgeo, MNR," whose assistance was very helpful in my field examination of paleontological materials.

Reviewers A.S. Alekseev and A.Yu. Rozanov

REFERENCES

Alekseeva, R.E., The Devonian of the Mongolian People's Republic, *Dokl. Akad. Nauk SSSR*, 1990, vol. 313, no. 5, pp. 1184–1187.

Alekseeva, R.E., *Biostratigrafiya devona Mongolii* (Devonian Biostratigraphy of Mongolia), Moscow: Nauka, 1993.

Alekseeva, R.E., Mendbayar, B., and Erlanger, O.A., *Brakhiopody i biostratigrafiya nizhnego devona Mongolii* (Brachiopods and Lower Devonian Biostratigraphy of Mongolia), Moscow: Nauka, 1981.

Dergunov, A.B. and Luvsandanzan, B., Stratigraphy of Deposits Filling Superimposed Structures in Northwestern Mongolia, in *Problemy geologii Mongolii* (Problems of Mongolian Geology), Ulan Bator: Akad. Nauk Mong. Nar. Resp., 1970, pp. 4–21.

Dergunov, A.B. and Luvsandanzan, B., Superimposed Structures of Northwestern Mongolia, in *Materialy nauchnoi konferentsii: "30-letie geologicheskoi sluzhby MNR"* (Proceedings of Scientific Conference: "30 Years of the Geological Survey of the Mongolian People's Republic"), Ulan Bator: Gosizdat, 1971, pp. 24–48.

Dergunov, A.B., Luvsandanzan, B., and Pavlenko, V.S., *Geologiya Zapadnoi Mongolii* (Geology of Western Mongolia), Moscow: Nauka, 1980.

Dergunov, A.B. and Markova, N.G., *Zony Mongol'skogo Altaya. Tektonika Mongol'skoi Narodnoi Respubliki* (Zones of the Mongolian Altai. Tectonics of the Mongolian People's Republic), Moscow: Nauka, 1974.

Dubatolov, V.N., Correlation of Middle Devonian Deposits in Siberia and Ardennes (Based on Studied Tabulata), in *Biostratigrafiya pogranichnykh otlozhenii nizhnego i srednego devona* (Biostratigraphy of the Lower–Middle Devonian Boundary Deposits), Leningrad: Nauka, 1982, pp. 58–64.

Resheniya Vsesoyuznogo soveshchaniya po razrabotke unifitsirovannykh stratigraficheskikh skhem dokembriya, paleozoya i chetvertichnoi sistemy Srednei Sibiri. Chast' II, srednii i verkhnii paleozoi (Resolutions of the All-Union Conference for Elaboration of Uniform Stratigraphic Schemes of the Precambrian, Paleozoic, and Quaternary Systems in Central Regions of Siberia: Part II. Middle and Upper Paleozoic), Leningrad: Vses. Geol. Inst. 1982.

Rzhonsnitskaya, M.A., *Biostratigrafiya devona okrain Kuznetskogo basseina* (Devonian Biostratigraphy in Marginal Zones of the Kuznetsk Basin), Leningrad: Nedra, 1968, vol. 1.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 176–179. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 81–84.
Original Russian Text Copyright © 1997 by Bragina, Vitukhin.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Radiolarians from Cretaceous Deposits of the Maini–Kakyine Ridge, Koryak Highland

L. G. Bragina and D. I. Vitukhin

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia

Received October 10, 1994; in final form, October 16, 1995

Key words: *Cretaceous deposits, radiolarians, foraminifers, Koryak Highland.*

Cretaceous–Paleogene deposits represented by thick volcano-sedimentary sequences are widespread in the Maini–Kakyine Ridge area (figure). The problem of the stratigraphic subdivision of these deposits has long been discussed, becase their paleontological characteristics were poorly known. Comprehensive study and detailed sampling for foraminifers were carried out in 1963–1964 to solve this problem (Tarasenko *et al.*, 1970). As a result a series of formations has been distinguished: the Khakina Formation of Maastrichtian age with *Inoceramus shikotanensis*, the Inetyvayam Formation of Danian–Paleocene age with *Rzhehakina epigona*, the Ivtygyn Formation of Danian–Paleocene age with *Rzhehakina epigona*, the Inochvivayam Formation of Paleocene age with *Globigerina nana* and *Acarinina primitiva*, and the Ilpin Formation of Eocene–Oligocene age. Radiolarians were originally identified from deposits of the Inetyvayam Formation and studied in thin sections by Zhamoida. The age was determined in the wide Cretaceous–Paleogene range (Zhamoida *et al.*, 1963).

At present, a procedure of separation of radiolarians from different rocks, including siliceous, by means of dissolving them in a dilute solution of hydrofluoric acid (HF) has been developed that allows an isolation of whole shells of radiolarians from such sequences.

In 1986, researchers from the Geological Institute, Russian Academy of Sciences, studied and sampled radiolarians (samples by K.G.Kazakov) from a section exposed along the Inochvivayam River, a left upper tributary of the Vyvenka River, which is represented from the base upward as follows.

The Khakina Formation:

Dark gray and brownish-gray basaltic agglomerate lavas, the thickness is 50 m. Sixty meters of the section are unexposed.

The Inetyvayam Formation:

(1) Medium to small-pebbled, sometimes bouldery conglomerates, 30 m thick. Ten meters of the section are unexposed.

(2) Sandy, small-detrital, claret siltstones, 28 m thick.

(3) Rhythmically interbedding dark gray laminated cherts, thin interlayers (0.1–0.15 m) of silicified tuffs, and highly siliceous, tuffaceous greenish-gray siltstones that grade into massive siliceous siltstones. A radiolarian assemblage of *Clathrocyclas hyronia* Foreman, *Stichomitra livermorensis* (Campbell et Clark), *Lithostrobus zhamoidai* Kasinzova, *Xitus asymbatos* (Foreman), *Phacodiscus* (?) sp., and *Hexacromyum* sp. of the late Campanian–Maastrichtian age is revealed at the base of the bed. The thickness is 50 m.

(4) Medium-grained, volcanogenic–terrigenous, dark-gray sandstones alternating with dark gray, tuffaceous siltstones. The thickness is 35 m.

(5) Massive, fine-grained, volcanogenic–terrigenous sandstones, 12 m thick.

(6) Gray, tuffaceous, sandy siltstones with individual thin interlayers of fine-grained, volcanogenic–terrigenous sandstones. The thickness is 12 m.

(7) Dark gray to black, fine-grained siltstones with interlayers of medium-grained, sandy, volcanogenic–terrigenous deposits. The thickness is 4 m.

(8) Rhythmic flyschoid interbedding of dark gray, medium-grained, volcanogenic–terrigenous, and tuffaceous sandstones. The thickness is 6 m.

The Inochvivayam Formation:

(1) Brown, tuffaceous, siliceous silts with oval carbonate concretions. The thickness is 15 m.

(2) Rhythmic flyschoid interbedding of gray volcanogenic–terrigenous medium-grained sandstones with sandy, brown to grayish-brown siltstones and gray siltstones. The thickness is 85 m.

(3) Rhythmic flyschoid interbedding of gray volcanogenic–terrigenous medium-grained sandstones with dark gray massive siltstones. The thickness is 20 m.

(4) Gray sandy siltstones, 8 m thick.

(5) Dark gray fine-detrital mudstones with carbonate concretions. The thickness is 70 m.

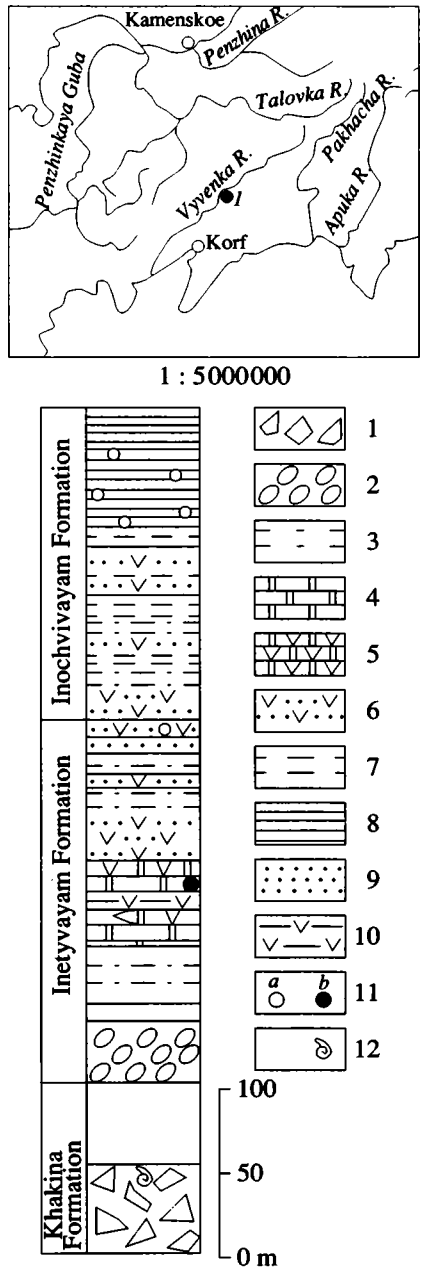
Forms of suborders Sphaeroidea, Discoidea and Larcoidea of Cenozoic appearance, undeterminable with more precision because of poor preservation, are

extracted from deposits of the Inochvuvayam Formation. The Nassellaria species are missing.

Volcanogenic and siliceous deposits are characteristic of the Upper Cretaceous sequences in the Koryak Highland. Their dating is problematic, as macro- and microfauna with a calcareous shell are, as a rule, missing from such deposits.

Deposits of the Inetyvayam Formation are not an exception in this respect. The lower part of the formation is represented by bouldery conglomerates with gritstone interlayers, the red–brown silts overlying them. The middle and upper parts of the formation are made up mainly of siliceous rocks. When desintegrating the samples, it was found that only several of them taken from the middle part of the Inetyvayam Formation appeared to have fauna. The radiolarian assemblage from siliceous rocks is represented by *Orbiculiforma renillaeformis* (Campbell et Clark), *Clathrocyclas hyronia* Foreman, *C. diceros* Foreman, *C. gravis* Vishnevskaya, *Lithostrobus zhamoidai* Kasinzova, *Xitus asymbatos* (Foreman), *Phacodiscus* (?) sp., *Hexacromyum* cf. sp., and by species of the Hagiastridae family. The assemblage is not diverse; representatives of the genus *Clathrocyclas* are dominant. All other species are subordinate. This is conditioned, on the one hand, by a selective preservation of shells, when fine skeletons might not be preserved (the selected forms bear evidence of lithification often being squeezed and crushed); on the other, it is not improbable that the assemblage was formed under neritic conditions as the prevalence of one or two species is very typical of neritic radiolarian assemblages (Kruglikova, 1974; Vitukhin, 1993).

The presence of *Orbiculiforma renillaeformis, Clathrocyclas hyronia*, and *Stichomitra livermorensis* in the assemblage allows its stratigraphic range to be limited by the late Campanian–Maastrichtian interval. The assemblage is correlative with coeval boreal assemblages of eastern Kamchatka (Zinkevich *et al.*, 1988), western Kamchatka (Zinkevich *et al.*, 1991), and Shikotan Island (Bragina, 1994) because of the presence of common species, especially *Clathrocyclas hyronia* and *Stichomitra livermorensis*. G.Yu. Averina found radiolarians in the same region in deposits of the Inetyvayam Formation (Chekhovich *et al.*, 1990). In Averina's opinion, the identified *Dictyopora* sp. suggests the late Campanian–Paleocene age of the assemblage. As no images of these forms were published, such a suggestion is hard to judge. Besides, Vishnevskaya described a more diverse assemblage from the same formation, whose deposits in the Inetyvayam River mouth area overlie sediments with *Inoceramus shikotanensis* and are overlain by beds with *Rzhehakina* (Bogdanov *et al.*, 1987). This sequence is similar to that described in this work. By the position in the section, Vishnevskaya assigns the assemblage to the Cretaceous–Paleogene. Unfortunately, no reliable data are available as yet on the Danian radiolarians from northeastern Asia. According to Hollis (1993), some species of the studied assemblage are found in Paleocene deposits. However, the assemblage discussed comprises no typical Cenozoic species, and this allows the enclosing deposits to be dated to the end of the Late Cretaceous (late Campanian–Maastrichtian).



The Upper Cretaceous–Lower Paleogene section of the Maini–Kakyine Ridge deposits (the inset shows the section locality on the map):

1, agglomerates; 2, conglomerates; 3, sandy siltstones; 4, cherts; 5, tuffite cherts; 6, siliceous siltstones; 7, siltstones; 8, mudtones; 9, sandstones; 10, tuffite siltstones; 11, (a) carbonate concretions, (b) level of radiolarian fauna; 12, *Inoceramus* Beds.

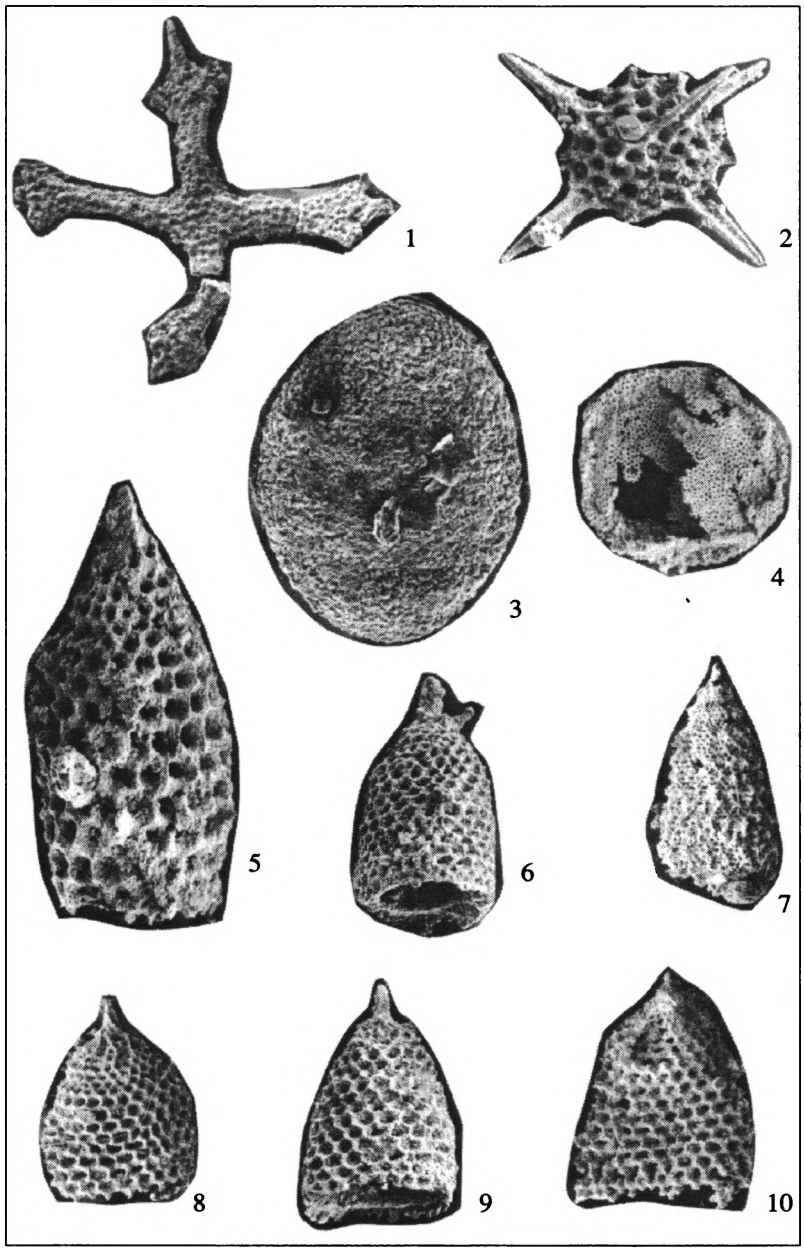


Plate. Radiolarian assemblage from the Inetyvayam Formation: (1) Hagiastridae gen. et sp. indet., ×200; (2) *Stylosphaera* sp., ×500; (3) *Orbiculiforma renillaeformis* (Campbell et Clark), ×200; (4) Gen. et sp. indet., ×200; (5) *Lithostrobus zhamoidai* Kasinzova, ×500; (6) *Clathrocyclas* cf. *diceros* Foreman, ×200; (7) *Xitus asymbatos* (Foreman), ×200; (8) *Clathrocyclas gravis* Vishnevskaya, ×200; (9) *Clathrocyclas hyronia* Foreman, ×200; (10) *Clathrocyclas* sp., ×200.

ACKNOWLEDGMENTS

This work was supported by the International Science Foundation, grant no. MR-6000.

Reviewers V.S. Vishnevskaya and I.A. Basov

REFERENCES

Bragina, L.G., Late Campanian–Maastrichtian Radiolarians of Shikotan Island, *Paleontologo–stratigraficheskie issledovaniya fanerozoya Dal'nego Vostoka* (Paleontological and Stratigraphic Investigations of the Phanerozoic in the Far East), Vladivostok: Dal'nevost. Kn. Izd, 1991, pp. 100–103.

Bogdanov, N.A., Vishnevskaya, V.C., Kepezhinskas, P.K., *et al., Geologiya yuga Koryakskogo nagor'ya* (Geology of the Southern Koryak Highland), Moscow: Nauka, 1987.

Chekhovich, V.D., Bogdanov, N.A., Kravchenko–Berezhnoi, I.R., *et al., Geologiya zapadnoi chasti Beringovomor'ya* (Geology of the Western Bering Sea Region), Moscow: Nauka, 1990.

Hollis, C.J., Latest Cretaceous to Late Paleocene Radiolarian Biostratigraphy: A New Zonation from the New Zealand Region, *Marine Micropaleontol.*, 1993, no. 21, pp. 295–327.

Kruglikova, S.B., Radiolarians in the Surface Sediments of the Sea of Okhotsk, *Okeanologiya*, 1974, vol. 15, no. 1, pp. 116–122.

Tarasenko, T.V., Mel'nikova, S.A., and Serova, M.Ya., Subdivision and Age Substantiation of Upper Cretaceous and Lower Paleogene Deposits of the Maini–Kakyine Ridge, Koryak Highland, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1970, no. 11, pp. 139–146.

Vitukhin, D.I., *Raschlenenie kainozoya Dal'nego Vostoka Rossii po radiolyariyam* (Subdivision of the Cenozoic by Radiolarians for the Far East of Russia), Moscow: Nauka, 1993.

Zhamoida, A.I., Lipman, R.Kh., Mikhailov, A.F., and Titov, V.A., Age of Siliceous and Volcanogenic Sequences of the Koryak Highland as indicated by Radiolarians, in *Materialy po geologii Dal'nego Vostoka i Zabaikal'ya* (Materials on Geology of the Far East and Transbaikalia), Leningrad: Vses. Nauch.–Issled. Geol. Inst. (VSEGEI)., 1963, pp. 75–104.

Zinkevich, V.P., Konstantinovskaya, E.A., Magakyan, R., and Bragina, L.G., Tectonics of the Ozernyi Peninsula, Eastern Kamchatka, in *Ocherki po geologii Kamchatki i Koryakskogo nagor'ya* (Notes on the Geology of Kamchatka and the Koryak Highland), Moscow: Nauka, 1988, pp. 87–102.

Zinkevich, V.P., Kolodyazhnyi, S.Yu., Bragina, L.G., *et al.*, Tectonics of the Eastern Framing Zone of the Kamchatka Median Mass of Metamorphic Rocks, *Geotektonika.*, 1994, no. 1, pp. 81–96.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 180–184. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 85–90.
Original Russian Text Copyright © 1997 by Vasil'ev.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

BRIEF COMMUNICATIONS

Biogeochemical Data Used to Identify Synchronous Stratigraphic Levels of the Middle Miocene in Volhynia–Podolia

A. N. Vasil'ev

Khar'kov State University, pl. Svobody 4, Khar'kov, 310077 Ukraine

Received May 5, 1994; in final form August 21, 1995

Key words: *event stratigraphy, biogeochemistry, middle Miocene, bivalves, gastropods, Volhynia–Podolia plate.*

Such objectives as detailed subdivision and correlation are principal in stratigraphy. To achieve them the recent practice of stratigraphic investigations focused a considerable attention on high-resolution event stratigraphy, a new promising branch of the science. It tackles the short-range (from a few hours to 100 ka) geological events that affected sedimentation and are recorded in sedimentary sequences. Events of this rank could be induced by tectonic, volcanic, climatic, oceanologic, sedimentologic, biologic, and, sometimes, extraterrestrial factors.

The category of short-range geological events includes fast regional tectonic movements, seismic sea waves, strong storms, volcanic eruptions, sharp changes in sea-water stratification or current system, climatic fluctuations, momentary phases in biota evolution or migration, and some other processes (Kauffman, 1988).

As a rule, all these events are of either local or regional significance. They are recorded in geological sections as variable hiatuses in sedimentation and thin sedimentary beds displaying specific structural, textural, geochemical, and other features. Investigating such sections, any scientist should first detect these indicators to decipher afterward the events and conditions responsible for their formation, and to correlate them, when possible, with global events providing a basis for more general stratigraphic correlation. At present, there are many attempts to define and test various methods for searching out exactly those stratigraphic levels and beds that correspond to the geological events in question. One of these methods is biogeochemical analysis.

MATERIALS AND ANALYTICAL PROCEDURE

To demonstrate the possibilities of the biogeochemical method I present here results on inferred indicators and respective stratigraphic levels of short-term events in the upper Badenian (middle Miocene) deposits of Volhynia–Podolia. I studied molluscan shells (21 species of Bivalvia and Gastropoda) sampled from 17 exposures of Podgor'e and Ternopol beds in the Lvov, Ternopol, and Khmel'nitski regions (Fig. 1). The middle Miocene deposits of Volhynia–Podolia are well studied and supplemented with complete paleontologic characteristics, thus being favorable objects for biogeochemical investigation.

The Podgor'e Beds consisting of quartz to glauconite–quartz sands and widespread in the northeastern and eastern parts of Volhynia–Podolia are up to 7 m in thickness. They bear abundant bivalve and gastropod shells of perfect preservation degree. Predominant forms are represented by *Glycymeris pilosa deshayesi* (May), *Nucula nucleus* (Linne), *Ostrea edulis degitalina* Dub., *Lucinoma borealis* (Linne), *Linga columbella* Lam., *Venus multilamella* Lam., *Cardites duboisi* (Desh.), *Turritella bicarinata* Eichw., *Natica millepunctata* Lam., and *Conus dujardini* Desh. In addition to mollusks, the Podgor'e Beds enclose abundant foraminifers, bryozoans, ostracodes, sea urchins, and other fossils.

The Ternopol Beds comprise *Lithothamnion* Limestone and calcareous clays, whose thickness is up to 10 m. They show irregular distribution patterns of molluscan

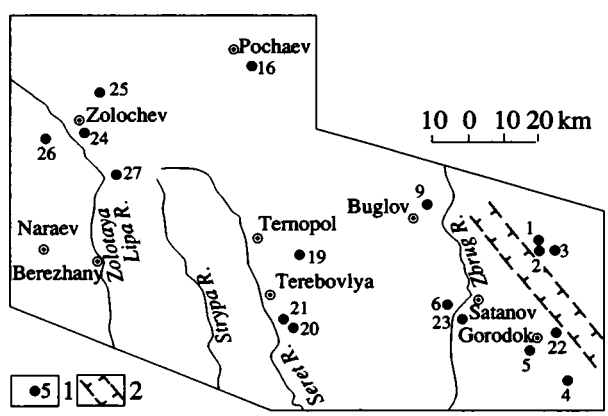


Fig. 1. Studied localities of middle Miocene deposits in Volhynia–Podolia: (1) exposures and their number; (2) the Podolia structural-geochemical zone.

Average concentrations of some chemical elements in the middle Miocene molluscan shells from Volhynia–Podolia

Species and number of analyses (in brackets)	Concentration, ppm							
	Mg	Sr	Ba	Ti	Mn	B	Cu	Ba
Nucula nucleus (28)	430	2300	1700	91	88	8.0	1.9	90
Glycymeris piloca deshayesi (151)	420	2900	1200	80	94	9.0	1.7	200
Ostrea edulis degitalina (192)	1080	1100	700	86	116	9.8	1.5	80
Linga columbella (32)	380	1900	1600	84	87	10.5	1.5	100
Lucinoma borealis (64)	400	2200	1300	87	86	11.6	1.4	50
Glans rudista (22)	570	2300	1100	91	90	8.6	1.4	250
Cardites duboisi (30)	640	3900	1100	94	90	8.8	2.4	820
Venus multilamella (64)	360	2900	1600	89	91	9.0	2.2	280
Callista chione (37)	330	2600	1300	80	85	8.0	1.9	510
Corbula gibba (16)	350	1700	900	91	89	7.7	1.7	430
Chama gryphoides (16)	650	2900	1300	118	96	10.0	2.3	470
Gibbula buchi (25)	360	2700	2500	91	82	7.1	1.9	150
Oxystele orientalis (50)	310	2600	2300	90	88	7.3	1.9	120
Astraea meynardi (24)	370	1900	1800	92	92	7.6	1.6	110
Turritella bicarinata (27)	410	2500	1000	93	88	7.0	1.7	260
Conus dujardini (29)	320	2000	700	82	85	7.3	2.0	400

shells generally representing such taxa as *Ostrea edulis degitalina, Chama gryphoides* Linne, *Panopaea meynardi* Desh., *Oxystele orientalis* (Cossm. et Peyr.), and *Bittium deforme* (Eichw.).

Prior to powdering, all sampled shells were freed of impurities, washed in distilled water, and dried at a temperature of 100°C. After mixing with ammonium chloride buffer, powdered samples were analyzed by the emission spectroscopy method using spectrograph STE-1 (Vasil'ev and Zhuravel', 1988a). The total number of analyzed samples is over 800. Average concentrations of some chemical elements in the shells are shown in the table. Other elements, whose concentrations were also measured, are Si, Al, Fe, Pb, Zn, Ni, Co, Ag, La, and Y. Processing of analytical data was performed by using multivariate statistic methods, for instance, the factor analysis, which considerably reduces the number of initial indications while preserving the original information in general.

Diagenetic alterations of shells were estimated using a special procedure described earlier (Vasil'ev and Borisenko, 1989). The estimation suggests that shells from both the Podgor'e and Ternopol beds are usually of a suitable preservation degree and do not show significant changes in the initial chemical composition in response to postsedimentation alterations. Precisely these shells were used in this study.

RESULTS AND DISCUSSION

Prior to the discussion of the results, I should note two favorable sides of biogeochemical analysis that are useful in elucidating problems of high-resolution event stratigraphy.

First, the structure of organic exoskeletons, in particular of molluscan shells, is capable of retaining (under a certain degree of diagenetic alterations) the chemical composition formed during the lifetime of an organism and reflecting the medium conditions of that time (Weber, 1977).

Second, as is commonly accepted (Walls *et al.*, 1977), chemical elements are concentrated in exoskeletons either as a result of metabolic reactions in organisms, or due to adsorption directly from their habitat medium. Ideally, this offers a possibility to detect different categories of past events, from physical and biotic, which are well manifested in lithologic and biotic changes, to variable chemical effects, including those that insignificantly transform sedimentation processes and biocoenoses.

Available data (Vasil'ev and Borisenko, 1990) show that chemical compositions of organic skeletons originally depend on hydrochemical conditions in the habitat basins. Accordingly, we may assume that events that were responsible for the basin enrichment in particular trace elements should be recorded in the geochemistry of molluscan shells.

Geochemical anomalies in the late Badenian sea of Volhynia–Podolia were produced by the Podolia structural–geochemical zone located in the southwestern marginal part of the Ukrainian Shield. This zone is related to the synonymous deep-seated fault of northwestern orientation, which disrupts the basement of the Volhynia–Podolia plate outside the shield area (Fig. 1).

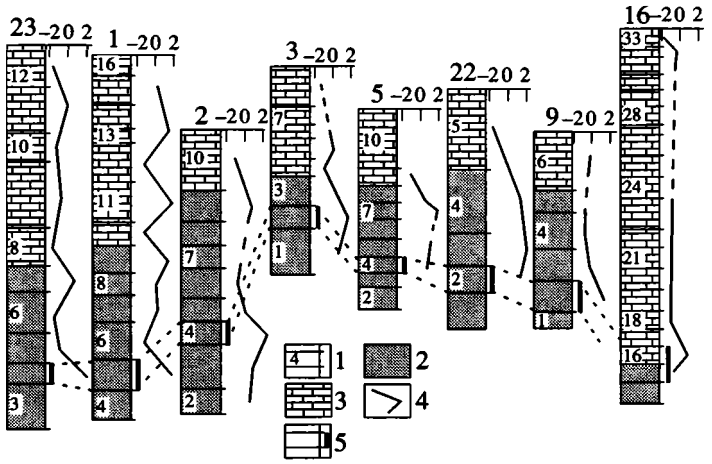


Fig. 2. Correlation of upper Badenian deposits in the southeastern Volhynia–Podolia based on biogeochemical data: (1) bed and its number; (2) sand, Podgor'e Beds; (3) *Lithothamnion* Limestone, Ternopol Beds; (4) variation curves for $\frac{Ba \cdot Cu}{B}$ indices (data of factor analysis); (5) interval of high Ag concentration in molluscan shells; column numbers correspond to locality numbers in Fig. 1.

The crystalline basement of the Podolia zone is enriched in such elements as Pb, Cu, Bi, Ba, La, Ce, Nb, P, and F (Galitskii *et al.*, 1984). Like many other diagonal tectonic fractures of Volhynia–Podolia, the Podolia fault was activated in the middle Miocene time in response to folding and thrust deformations in the Carpathian Mountains (Znamenskaya and Chebanenko, 1985). This event was presumably responsible for the excessive influx of endogenic mineralized fluids with high concentrations of certain trace elements into the late Badenian basin, whose southeastern part became enriched in Ba, Cu, Pb, and other components as compared to its northwestern area (Vasil'ev and Zhuravel', 1988b).

Fig. 2 illustrates distribution patterns of $\frac{Ba \cdot Cu}{B}$ indices inferred for the *Glycymeris pilosa deshayesi* shells distributed through the studied litho-stratigraphic columns of upper Badenian deposits, which are exposed in central and northeastern parts of the Volhynia–Podolia plate. The indices were estimated using the factor analysis of data on the chemical composition of shells collected from the upper Badenian deposits of the region. As these indices are of the same, or almost of the same type for many studied taxa, e.g., for gastropods Trochidae and bivalves Veneridae and Lucinidae, they can be considered as universal for the stratigraphic interval in question. I should also note that the initial data base included average concentrations of all elements estimated on the basis of 3–9 samples selected from each bed of this interval.

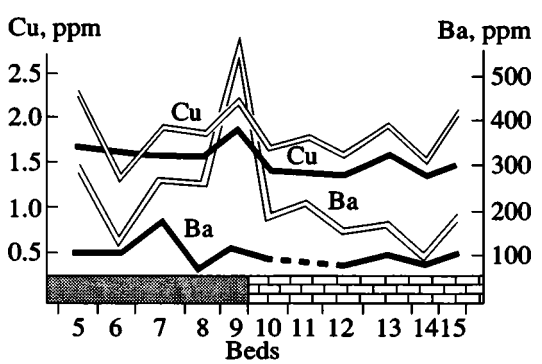


Fig. 3. Variation curves of Ba and Cu concentrations in shells of *Glycymeris pilosa deshayesi* (double lines) and *Linga columbella* (solid lines) from Exposure 1.

The highest values of $\frac{Ba \cdot Cu}{B}$ index correspond to shells enriched in barium and copper, while their negative values indicate samples with inverse proportions between these elements and boron. As is known, linear factor analysis affords an opportunity to evaluate variables that cannot be measured directly. In this case, I believe, it depicts among all possible factors the influence of regional tectonic processes on the inferred biogeochemical indices.

The diverse geological records hinder the detailed interpretation of past events; however, the data obtained still indicate that we can distinguish several short phases of barium and copper influx into the paleobasin. Exposure 1 with the most complete sequence of Podgor'e Beds displays four of these events, which are confined to regressive rhythms of sedimentation. In the Podgor'e Beds, these rhythms are marked by inequigranular sand strata enclosing cherty pebbles and gravel, whereas in the Ternopol Beds, they correspond to the levels of *Lithothamnion* Limestone with sandy admixture. Distribution patterns of chemical elements do not contrast equally for different molluscan taxa, as is evident from Fig. 3 illustrating the distribution of

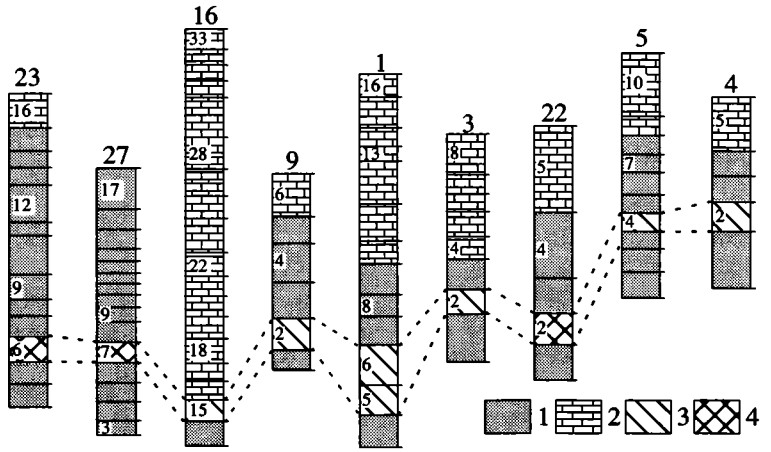


Fig. 4. Stratigraphic level of high La and Y concentrations in molluscan shells: (1) sand, Podgor'e Beds; (2) *Lithothamnion* Limestone, Ternopol Beds; (3) interval of high La concentration; (4) interval of high La and Y concentration; column numbers correspond to locality numbers in Fig. 1.

absolute Ba and Cu concentrations in the stratigraphic sequences of *Glycymeris pilosa deshayesi* and *Linga columbella* shells.

The periodic variations of Ba and Cu contents along the sequence and their peak concentrations confined to shells from regressive rhythms confirm the idea that the biogeochemical anomalies were formed by endogenic processes. The peak concentrations of these elements and Pb marked the activity peaks of long-lived fracture zones during phases of tectonic rises. This geochemical effect is typical of the southeastern part of the basin, which was under the influence of the Podolia structural–geochemical zone. As can be seen from Fig. 2, northward of this zone in Exposure 9, and also in Exposure 16 far remote from the Podolia fault, indices describing barium and copper distribution in shells are either negative or approaching zero, and their variations are of a low amplitude and irregular.

In addition to barium and copper, boron is also the component controlling values of $\frac{Ba \cdot Cu}{B}$ index. In shells from eastern and central parts of the region, concentrations of the last element are monotonous and vary within a narrow range close to the background value. For the western part however, boron is a typomorphic element concentrated in shells. In contrast, barium and copper concentrations are low here, and variations of $\frac{Ba \cdot Cu}{B}$ index mainly depend on values of boron content. Apparently, the influence of the Podolia structural–geochemical zone on the hydrochemistry of the Badenian basin was decreasing in the western direction. In the western area, sedimentary material was mostly derived from the Carpathian Mountains, which were rising and volcanically active at the late Badenian time (Kruglov *et al.*, 1985). The influx of erosion products and boron-rich fluids, which was provoked by volcanic eruptions, should eventually increase the boron content in sea water and, accordingly, in molluscan shells.

In the southeastern part of the region, shells from one of the Podgor'e Beds, which are rich in Ba, Cu, and Pb, display as well high contents of Ag (Fig. 2), La and Y (Fig. 4). The abnormally high concentrations of Ag (0.32–1.0 ppm versus the background value of 0.025 ppm) were measured here in *Glycymeris pilosa deshayesi, Ostrea edulis degitalina, Venus multilamella*, and some other shells. This anomaly is typical of the indicated area, yet has not been traced in the northwestern part of the region.

An area of high La concentrations in molluscan shells (15–25 ppm) is wider. In some cases, e.g., in exposures 22, 25, and 27, such shells also accumulated yttrium, whose concentration can be as high as 12 ppm.

This lateral discordance of geochemically anomalous zones seems to be a result of the distinct migration ability of different elements. Otherwise, this can reflect the interference of several events different in character and intensity. For instance, we probably deal with a geochemical imprint produced by terrestrial acid to intermediate volcanism that was active in the Carpathian Mountains during the middle Miocene. In the western part of the region adjacent to the mountains, the studied shells show the most contrast variations in boron contents. This element is very characteristic of volcanic products, and consequently can be used in the indicated area as the main marker of synchronous stratigraphic levels.

CONCLUSION

The data obtained in this work show various possibilities of biogeochemical methods in detecting those levels of geological sections that yield information on short-term events. They allow me to highlight the following points:

(1) In the southeastern part of the region, the detailed correlation of upper Badenian sequences can be based on distribution patterns of Ba, Cu, and Pb in molluscan shells. The inferred patterns suggest a rhythmical influx of these elements into the paleobasin and individual features of every rhythm.

(2) These features may reflect certain changes in the leading processes, for instance, changes in the activity of tectonic movements and related fluctuations in fluid infiltration through fracture zones, as it was in our case. Biogeochemical anomalies, when they are induced by tectonic events of variable intensity, may differ only due to natural metabolic and chemical barriers affecting one or another element accumulation in organic structures. At the same time, geochemical effects of subordinate rank can be superimposed on manifestations of leading regional processes and thus provide individual features to each sedimentation rhythm.

(3) Biogeochemical data facilitated correlation between separate sections of polyfacial Podgor'e and Ternopol beds in the Khmel'nitski, Ternopol, and Lvov regions of Ukraine.

(4) Biogeochemical method is an appropriate tool for detecting synchronous stratigraphic levels of local significance, which mark one and the same regional event and thus meet all requirements set for the reference beds.

ACKNOWLEDGMENTS

I am sincerely grateful to Prof. V.P. Makridin for critical discussion of the manuscript and helpful comments.

Reviewer V.A. Sochava

REFERENCES

Galitskii, L.S., Gorlitskii, V.B., Kipnis, L.A., *et al.*, *Geologiya i metallogeniya Ukrainskogo shchita. Ob'yasnitel'naya zapiska k komplektu kart masshtaba 1: 1 000 000* (Geology and Metallogeny of Ukrainian Shield. Explanatory Notes to the Map Series, Scale 1: 1 000 000), Kiev: Mingeo UkrSSR, 1984.

Kauffman, E., Concepts and Methods of High-Resolution Event Stratigraphy, *Annual Rev. Earth. Planet. Sci.*, 1988, vol. 16, pp. 606–654.

Kruglov, S.S., Smirnov, S.E., Fil'shtinskii, L.E., *et al.*, *Geodinamika Karpat* (Geodynamics of the Carpathian Mountains), Kiev: Naukova Dumka, 1985.

Vasil'ev, A.N. and Borisenko, Yu.A., Biogeochemical Criteria for Diagenetic Appraisal of Fossil Molluscan Shells, *Dokl. Akad. Nauk SSSR*, 1989, vol. 305, no. 6, pp. 1474–1477.

Vasil'ev, A.N. and Borisenko, Yu.A., Ethologo-Trophic Affinity of Fossil Mollusks Recorded in Chemical Composition of Their Shells, *Vestn. Khar'k. Univ.*, 1990, no. 345, pp. 14–19.

Vasil'ev, A.N. and Zhuravel', N.E, Ammonium Chloride as a Buffer in Spectral Analysis of Trace Elements, *Vestn. Kharkov. Univ.*, 1988a, no. 325, pp. 46–48.

Vasil'ev, A.N. and Zhuravel', N.E, Geochemical Zoning of Late Badenian Basin in the Volhynia–Podolia Region Based on Biogeochemical Data, *Dokl. Akad. Nauk Ukr SSR, Ser. B: Geol. Khim. Biol. Nauki*, 1988b, no. 7, pp. 3–6.

Wallis, R.A., Ragland, P.C., and Crisp, E.L., Experimental and Natural Early Diagenetic Mobility of Sr and Mg in Biogenic Carbonates, *Geochim. Cosmochim. Acta*, 1977, vol. 41, pp. 1731–1737.

Weber, J.N., The Incorporation of Strontium into Reef Coral Skeletal Carbonate, *Geochim. Cosmochim. Acta*, 1977, vol. 37, pp. 2173–2190.

Znamenskaya, T.A. and Chebanenko, I.I., *Blokovaya tektonika Volyno–Podolii* (Block Tectonics of Volhynia–Podolia), Kiev: Naukova Dumka, 1985.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 185–197. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 91–104.
Original Russian Text Copyright © 1997 by Lazarev.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Peculiar Features of Typification in Stratigraphic Classification

S. S. Lazarev

Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117868 Russia

Received March 19, 1994; in final form December 5, 1994

Abstract—Peculiar features of typification in stratigraphy, i.e., the regulation of the entitative aspect of a stratigraphic unit and its legalization in the stratotype, were analyzed. These procedures inevitably led to the repudiation of the hierarchical principle in typification, which made the priority principle an obstacle to the elaboration and perfection of stratigraphic classification. These peculiar features of typification took shape in parallel with the strengthening of the chronostratigraphic paradigm. An analogy with biological systematization is used to show a possible way to solve the problem. A revision of the typification system in stratigraphy is proposed to make it similar to that in biology.

Key words: *stratigraphic classification, terminology, stratotype, boundary stratotype.*

To learn is easier than to lose the art
(A. Kestler, 1993, p. 97)

Typification in science usually occupies its proper place on the periphery because it relates to the essence of science only indirectly by executing auxilliary (technical) functions. However, views on typification in stratigraphy evolved in a peculiar way, which led to a situation in which problems of typification and entitative problems appeared to be intimately related. This very approach to the type in stratigraphy as to an entitative standard that characterizes a stratigraphic unit can be considered as a basic "apomorphy," which determined the deviation of stratigraphic typification from its traditional form, for instance, that used in biology.

Discussions in the course of the preparation of the paper for publication revealed one serious objection expressed by opponents that can drastically affect the logic of futher reasoning. This objection is based on a solely pragmatic approach and consists in the conviction that stratigraphic classification does not exist, cannot exist at all, and, therefore, the analogy with biological classification is invalid. The objection concerns first of all the general (international) stratigraphic scale. It is implied that (1) the hierarchy of strtaigraphic units does not necessarily relate to the entitative hierarchy; (2) there exists only a succession of geological events well coordinated in time and, thus, the revision of their recent hierarchy is unnecessary; and (3) only the more precise establishment of boundaries between known units (and filling possible gaps) without their significant revision is necessary. Accordingly, the general analysis and revision of the current global stratigraphic scale are not even assumed, and the proximity of the new, more precisely defined boundary to an earlier adopted one becomes one of the criteria for its selection.[1] This approach justifies the conventional character of the recent global stratigraphic scale; i.e., its ultimate goal is the conservation of the scale.

I believe that a more correct approach is to consider the global scale as both a reflection of the succession of geological events and also as a succession whose hierarchy reflects the scale of historical–geological processes. Accepting this approach, we can use an analogy with biological classification. Here I speak first of all about the hierarchical form of classification, as any stratigraphic scale is a result of the grouping of previously identified units into their entitative blocks of different ranks. The succession of units in the scale reflects their orderliness in time; while grouping elementary units into the higher subdivisions of the scale, we perform a procedure well comparable with the taxonomic classification in biology. Actually, the persistent readjustment of stratigraphic boundaries (i.e., the modification of their hierarchy) shows that stratigraphers pay attention not only to the correct time sequence of units, but also to their hierarchical relations in the stratigraphic scale, i.e., in the scheme of stratigraphic classification. In this case, the analogy is justified in general by the nonaccidental character of biotic assemblages and also by the fact that the historical component plays a significant role in both classifica-

[1] Since the 1960s, works on defining boundaries of a global scale, i.e., the selection of a more distinct (more correlative) boundary, were performed by working groups within the framework of international projects.

tions and that biota evolution represents the most important basis for calibrating the geochronologic scale, at least for the Phanerozoic. Of course, any analogy is not yet a proof, but it is a suitable opportunity to analyze and explain certain situations. Here, analogies will be used to make "new" suggestions on typification in stratigraphy, which are unfamiliar and, thus, unusual for many stratigraphers, more understandable.

Before going to a discussion of peculiar features of typification in stratigraphy, it seems reasonable to present a brief analysis of the stratigraphic paradigm, against the background of which the system of typification developed.

THE CONCEPT OF CHRONOSTRATIGRAPHY

At present, the notion of "chronostratigraphy" has different meanings. In stratigraphic practice, it commonly implies an element of stratigraphy that is concerned with the correlation of stratigraphic units of any stratigraphic scale, or stratons, by Meyen's terminology (Meyen, 1989) as well as stratigraphic scales themselves to the global scale. There is nothing reprehensible in this approach, though, in this case, the term "chronostratigraphy" bears certain pretension to monopolize the time.

Another thing is the concept of chronostratigraphy, because here time is, in fact, separated from real geological processes and is even opposed them. That is why chronostratigraphic units in the hierarchy of categories of stratigraphic classification can be distinguished in addition to and along with other units such as lithostratigraphic, biostratigraphic, and others as if they are time-independent. In the International Stratigraphic Guide published in 1978 (with H. Hedberg as its inspirer and editor), chronostratigraphy was unequivocally defined as "that element of stratigraphy which is concerned with the organization of strata into units based on their age relations" (*International* ..., 1978, p. 8). Other elements of stratigraphy are by definition concerned only with the subdivision of rock sequences according to their properties.

The history of elaboration of this concept was discussed in the publication by Hancock (1977) and was, to a large extent, connected with the name of Hollis Hedberg who started this work as early as in the early 1950s. Chronostratigraphy conquered to a variable degree the minds of recent stratigraphers though it affected different stratigraphic schools in different ways. Reflections of this concept can be found in the stratigraphic guides of any country and in the minds of the majority of stratigraphers. The most convincing critique of the chronostratigraphic concept made by Schindewolf (1975) is considerably weakened by the fact that its author also considered, as follows from the text of his monograph, the stratigraphic scale as a standard for correlation. Because of this, evidently, he denied the importance of stratotypes at all.

Since then, the concept remains principally unchanged. During recent decades, much attention has been paid to the selection of the Global Boundary stratotype and section points (GSSP), which are considered to be important "in order to define without doubt an instant of geologic time ... The correctly selected GSSP gives an actual point in rock, not an abstract concept—all other methods can prove to be diachronic" (Cowie *et al.*, 1986, p. 5). However, the problem is that this point is real only in the particular section, whereas its correlation beyond the area of the pertinent facies distribution is impossible without a conceptual basis.

Krasilov (1977) was probably the first to note the incompetentness of considering chronostratigraphy on a level with other elements of stratigraphy such as lithostratigraphy, biostratigraphy, and others. He and, later, Jaeger (1981) and Johnson (1992) justly noted that chronostratigraphy is a concept, a theoretical framework rather than a method. As for the methods themselves (litho-, biostratigraphy, and others), they provide, according to this concept, *a priori* diachronic boundaries though their age variability is in principle undeterminable.

The chronostatigraphic concept was preceded by the concept of the geochronological scale that was in use already at the initial stage of elaboration of stratigraphic classification and was used in parallel with the stratigraphic one. Moreover, this duality itself implied, though subconciously, a certain independence of time relative to geological processes. Here, we are approaching, at last, the rational point that can be found in the concept of chronostratigraphy. Such notions as geochronological units, chronostratigraphic units, and correlative units, which appeared sequentially, have distinct conceptual relationships and reflect the desire of stratigraphers to construct some universal time scale independent of the real physical substratum, which is variable both between different regions and within a single region. The theoretical basis for the creation of a global scale as a time standard is the principle of the chronological interchangeability of stratigraphic properties known as Meyen's principle. It was formulated not long ago, in 1974 (Meyen, 1989), when the framework of the global scale was already elaborated. This principle allows any stratigrapher to tear himself away from the substratum of the stratigraphic unit first established somewhere and to use the name of this unit in those areas where its stratigraphic features, according to which it was defined, are expressed differently or absent at all. Such subdivisions, alienated from the physical substratum despite its basis in real historical processes and their relationships, should not be termed as chronostratigraphic because units of the last type already acquired a reputation of phantoms related to the concept of absolute physical time. To a certain extent, this also concerns geochronological units playing the

role of time equivalents of stratigraphic units.[2] The most convenient and unequivocal term "correlative units" was suggested for units in question by Zubakov (1978, 1980) who considered them to oppose the registration units that are directly observable.

The chronostratigraphy concept cannot be separated from the concept of conventional stratigraphic units. Indeed, if uniform continuous physical time serves as a reservoir for certain succession of geological rocks (historically, units of a global scale were defined without their intercorrelation similar to the construction of the tower of Babel) then it is logical to legalize, arbitrarily but precisely, boundaries between conventionally defined intervals in a certain section. In fact, such a harmonic coupling of chronostratigraphy with the conventional character of the global scale was embodied in the draft version of the English stratigraphic guide (Russian translation by Zhamoida *et al.*, 1969). The conventional character of stratigraphic units and the conventional character of their boundaries are something principally different (see below). When one speaks of boundaries, the word "convenience" is used: the lower boundary stratotypes of chronostratigraphic units are selected to make them convenient "so that the point marking the boundary (the golden spike) is marked by the distinct change in faunal, floral, and other properties observed at this boundary" (Holland, 1979, p. 9). This means that geological time inseparable from geological processes is not monotonous and uniform like physical time. This, in turn, means that stratigraphic boundaries (signals of geological time) of different historical–geological significance and geographic distribution could become the basis for defining natural stratigraphic units of variable ranks. Permanent revision of boundaries, i.e., search for stratigraphic levels most appropriate for correlations, means itself the negation of the convention principle.

The chronostratigraphy model is based on the existence of a general (physical) time axis that is divided by the Global boundary stratotype and section points (GSSP) into intervals corresponding to stratigraphic units. Each of these points "fixes a certain moment of geological time (time signal) in the geochronological scale" (*Stratigraficheskii* ..., 1992, p. 75). The time axis with such points serves as a standard to estimate the age of geological events. By the universal scale calibration, only time is "extracted" from real sections (stratotypes). "The peculiar feature of chronostratigraphic units is that their establishment and delimitation are based on correspondence to a certain interval of geological time rather than on particular physical properties" (Stepanov and Mesezhnikov, 1979, p. 355). Nonetheless, advocates of chronostratigraphy consider units of this scale to be stratigraphic. Geochronologic units should exist parallel with these latter ones, because "geological time is nonmaterial" (*ibid.*, p. 356). From this standpoint, chronologic and stratigraphic units are undoubtedly synonymous. More importantly, the chronostratigraphic concept gives priority to the temporal subdivision. "The chronostratigraphic procedure completely changed the classification logic: in traditional scales, first to be defined were geological events and then, corresponding intervals of geological time, whereas in chronostratigraphy, the first to be divided is time. Further, conventional time intervals are superposed on a succession of events regardless of their inner unity" (Krasilov, 1997, p. 32). The chronostratigraphic procedure logically requires conventional standards, conventional in the sense that the relative significance of time signals is not quite important, i.e., problems of hierarchy and classification do not need to be solved.

Though the chronostratigraphic concept took a firm place in stratigraphers' minds during recent decades, I believe that this place should be occupied by the traditional stratigraphic concept, according to which geological processes and geological time are indivisible. The acceptance of the stratigraphic paradigm would mean that reasoning about diachronous character of the geological record is senseless. Perhaps it would be better to speak about the isochronism presumption similar to presumptions in phylogeny. In this case, the closest analogy is a presumption of inheritance (Rasnitsyn and Dlusskii, 1988). For instance, if we observe a similar succession (homotaxy) of lithological units in a certain region, then pertinent lithological boundaries can be considered to be isochronous unless there is evidence to the contrary. The diachronous character of lithological boundaries can be determined, as often happens, by more precise methods based on other criteria, for instance, by biologic (biostratigraphic) methods. When using the biostratigraphic method, the diachronous nature of boundaries indicated by one fauna type is established based on some other fossil group, which provides more precise dating. Regardless of what resolution degree is provided by a more sophisticated method, there is no guarantee that further studies will not allow boundaries to be drawn even more precisely; i.e., we may discover their diachronism through the perfection of the same method or through a new, more precise one. Nobody can determine the precision limit. One can only assume (as was done once by D.V. Nalivkin) that in biostratigraphy it is limited by the size of fossils. Inasmuch as we cannot speak about some absolute, once and forever established isochroneity in every particular case, the discussion about "isochronism" notion in general, similar to that practiced in chronostratigraphy, is senseless.

Unfortunately, the fundamental demarcation between chronostratigraphy and traditional stratigraphy still remains almost inperceptible even for those

[2] Schindewolf was evidently right considering this parallel system of notions to be superfluous. The objections of Ruzhentsev (1977), another opponent of stratotypes, were not supported by any evidence. It is difficult to consider Ruzhentsev's suggestion to proceed not from stratigraphy to geochronology but, on the contrary, from geochronology to stratigraphy as a reasonable argument; this would violate the fundamental principle of stratigraphy—Stenon's principle.

stratigraphers who reject the concept of physical time in stratigraphy. Let us remeber, for instance, attempts to understand whether d'Orbigny and Oppel attached chronostratigraphic meaning to their zones or not. It is quite evident that the earliest generations of stratigraphers did not think about it and perceived the succession of fossils in the rock sequences as a time succession and nothing more. In those happy times the analytical scalpel, sharpened by the chronostratigraphic concept, did not yet dismember a body of stratigraphy into chrononstratigraphy and other kinds of stratigraphy. Zones of any kind used in stratigraphy bear a temporal aspect. So-called chronozones are used because they are acknowledged to be convenient as a universal interregional language. Nevertheless, when adopting these units, stratigraphers were not guided by the consideration whether they reflect time or not, they just wondered how narrow is the interval of a zone, how far is it traceable, and how easy is it recognizable.

In its most consistent version (the concept of physical time + conventional character of units of the global scale), chronostratigraphy requires accredited standards—unit stratotypes and, even better, boundary stratotypes. In this case, the historically determined content of units of the global scale also needs legalization and regulatuion after insignificant corrections in the position of unit boundaries. The recent typification system in stratigraphy bears peculiarities uncommon for typification in other sciences and is conditioned by the chronostratigraphic paradigm. In addition to the tempting simplicity of the artificial classification (Krasilov, 1977), the acceptance of this system is also alluring because it promises a certain absolute status to be reached in the nearest future. Indeed, chronostratigraphy, in fact, will exhaust itself when all the unit boundaries established by precise methods are fixed and officially approved. However, the elaboration of entitative classification in stratigraphy will become, sooner or later, the urgent problem.

STRATOTYPE AND BOUNDARY STRATOTYPE IN MODERN STRATIGRAPHY

Problems of typification in stratigraphy are determined by the fact that the notion of type—stratotype—bears not only a nomenclature meaning. At present, the notion of *stratotype* has at least three essentially different aspects: (1) a nomenclature type; (2) a standard for a uniform definition and understanding of the stratigraphic unit; and (3) an accredited conventional time interval—the universal standard of the geochronological scale. Differences between these aspects are not always recognized. This can be illustrated by citing the reference–methodical stratigraphic guide (Stepanov and Mesezhnikov, 1979) widely known in Russia (and in former USSR republics): (1) "one should agree with Sokolov's opinion that the stratotype guards the name, but not the content, of the stratigraphic unit" (p. 392); (2) "Stratotypes, like most important geological standards, are necessary for stratigraphic units of all kinds" (p. 388); and (3) "Stratotypes of chronostratigraphic units serve as standards for their definition" (p. 388). These three statements, corresponding to three different aspects of the stratotype notion, imply that the stratotype of a global scale must simultaneously perform all three functions.

During recent decades, the tendency of shifting from typification of stratigraphic units to typification of their boundaries is progressively growing. Accordingly, N.K. Erben suggested the term *boundary stratotype* (Zubakov, 1978), which already took roots in the second edition of the Russian stratigraphic guide (*Stratigraficheskii* ..., 1992). Attention to boundary typification means that the content (characteristics) of the unit is relegated to the background (the unit is just the interval between two boundaries), and special emphasis is given to the boundary. When the boundary has no proper name, the boundary stratotype fulfils exclusively the entitative function, or function of conventional temporal marker (depending on the approach to the nature of stratigraphic units and their boundaries) but not that of nomenclature.

There are two different theoretical arguments substantiating the necessity of transfering emphasis in stratigraphic investigations and, accordingly, in typification to stratigraphic boundaries. The first of them was most clearly expressed in the introductory chapter of the draft version of the English stratigraphic code (Zhamioda *et al.*, 1969). The necessity of typification of boundaries (marker points) was explained there by the theoretical nature of available chronostratigraphic scales: inasmuch as the natural standard scale is unknown, the ambiguously recognizable standard scale should be constructed "arbitrarily and by agreement" (p. 94). The further logic is as follows: since the succession of main stratigraphic units is already established, and these bear the proper names (for instance, Cambrian, Ordovician), then, to retain the names of these units, boundaries between them should be fixed. According to the authors of the aforementioned draft version, being fixed in stratotypes, the marker points will forever preclude confusion. Such views inherit and develop the above-discussed concept of chronostratigraphy though the authors did not use the term "chronostratigraphy."

The second, directly opposite argument favoring the necessity of stratigraphic boundary typification is of an essence nature, i.e., the emphasis in stratigraphic investigations is put on studies of events ("event stratigraphy"). In other words, boundaries acquire priority significance because they are considered to represent different "signals of space–time relationships of events or signals of geological time" (Zubakov, 1978, p. 17), and "it is sufficient to have only standards of these signals, i.e., of boundaries" (*ibid.*, p. 26).

Turning our attention from units to their boundaries, we change the specifics of investigations. It is known

that stratigraphers from different countries independently arrived at similar conclusions: (1) stratigraphic units bear characteristics, i.e., the maximum set of features (which can infinitely be supplemented); and (2) boundaries have substantiation (definition), i.e., the necessary and sufficient minimum of features that allows the unit boundaries to be traced (Murphy, see Johnson, 1979; Zubakov, 1978). Hence, the solution of a dilemma of conventionality–naturalness in relation to stratigraphic units and their boundaries need not be the same, i.e., the naturalness of the unit does not mean that the real positions of its boundaries can be defined in practice (Sokolov, 1971). The idea of the naturalness of stratigraphic units stems from the fact that they reflect "general regularities (stages) in the evolution of the litho- and biosphere, both interacting with each other and with other shells of the planet" (*Stratigraficheskii ...*, 1992, p. 25). For the Phanerozoic, the emphasis is usually placed on stages in evolution of biota because it is explicitly or implicitly assumed that the latter is the most sensible indicator of time in the evolution of geosystems.

Boundaries in the global scale have a conceptual character separated from the material substratum. In any particular section, many distinct boundaries can exist; each of these boundaries may be real and natural, however, the correlative (conceptual) boundary does not necessarily coincide with the most distinct one in a section or an area.

The gradual (stepwise) character of conceptual boundaries that are based on the complex of different features, whose changes often do not coincide, leads us to the necessity of their often subjective selection. The selection of the Silurian–Devonian boundary at the base of the graptolite *uniformis* Zone or the Devonian–Carboniferous boundary at the base of the conodont *sulcata* Zone does not necessary mean that these very levels are better substantiated; it means that at the moment they appeared to be most convenient and, thus, more natural (Meyen, 1989) in comparison with other nearby levels. The temporary fixation of these boundaries is justified by their necessity in geological practice (compilation of legends for geological maps). However, there is no need to legalize these boundaries in the particular section (in the boundary stratotype).

I am not against the indication of particular sections. However, it is one thing to give legible references to one or even several monofacies sections where one can clearly observe gradualness in the distribution of conventionally selected biotic groups (joint of contiguous phyletic zones) to define pertinent boundaries, which is reasonable and useful. However, it is quite another matter to use the defined point in the boundary stratotype as a certain time marker (chronostratigraphic standard), i.e., to impart definite juridical status to this point. In doing so, not just conventionality but double conventionality is legalized: the first is fixing the boundary precisely to the appearance of the *uniformis* or *sulcata* species; and the second is fixing not only the appearance level of a certain taxon, whose status may be changed in future, but also the point in the particular section. In the absence of gaps in the pertinent section, this point may be valid forever because it marks only a time and does not depend on our changeable concepts. In the first case, legalization is justified for stability reasons, but it should be changed when the old concept of the boundary dies off as happened with the Lower–Upper (Middle) Carboniferous boundary, which was previously placed at the base of the Namurian. In the second case, legalization (of the point in the time scale) theoretically does not depend on our changeable concepts; i.e., it is in principle aimed at eternal conservation. That is why conventionality of the first kind may be justified whereas the second one is harmful for entitative stratigraphy.

The gradual nature of processes whose imprints in the geological record mark boundaries gave rise to the idea of volumnary boundaries (Karpinsky, 1945; Khalfin, 1980), i.e., the transitional stratigraphic units, which were termed by Krasilov (1977) *stratoecotones* (again by analogy with the biologic term *ecotone*).

Gradualness and, consequently, conventionality are the immanent peculiar features of any boundaries in natural processes. An analogue of N. Bohr's principle of complementary properties, which is reformulated by Starobogatov (1968) to be applied for steady-state and evolutionary aspects of taxonomy, is evidently also suitable for stratigraphy: the more units we study and recognize in sections, the more difficulties we face when selecting the "natural" boundary. In physics, Bohr's principle, in Popper's opinion, was connected with the philosophy of instrumentalism, i.e., with the pragmatic approach. In stratigraphy (and biology), this principle similarly justifies conditional, often applied delimitation of stratigraphic units (taxons). However, it is not inconceivable that the paleoecosystem approach will some day allow this conditional character of stratigraphic boundaries to be overcome, which was expected by the adherents of the causal approach in stratigraphy (Krasilov, 1977; Meyen, 1989; and others).

Thus, the conventional character of the stratigraphic boundary is equivalent to gradualness or (in data extrapolation) the stepwise nature ("Schindewolf's steps") of the appearance and disappearance of those properties that are used for delimitation of stratigraphic units. It is clear that conventionality of this kind has nothing in common with the conventionality that was discussed earlier when considering the chronostratigraphic concept.

TYPIFICATION AND REFERENCE SECTIONS; STANDARDIZATION

Typification problems include fundamentally different aspects, which need to be properly termed to avoid confusion. The terms used here may seem inadequate;

however, they were not just invented but carefully chosen in order to cause the least harm to the tradition.

Inasmuch as the terminology of types in stratigraphy bears a clear similarity to that in zoological nomenclature (differing only in the added prefix "strato"), then the meaning of words "typification," and "stratotype" in stratigraphy should be preserved only in the sphere of nomenclature. In this case, the basic function of the stratotype will be the same as that of the type in biological nomenclature, i.e., the function of labeling and name stabilization. To successfully accomplish this function, the stratotype should fulfill the following requirements: (1) it should be the only one and accredited in accordance with (revised) rules of stratigraphic nomenclature; and (2) it should be established in accordance with the hierarchy principle; i.e., the stratotype of any subdivision should be represented by subdivision of the lower rank; for the local scale, the correlative zone and bed in the particular section can be considered to represent the unit of the lowest rank;[3] (3) when selecting synonymous names, the priority principle should be used, and, like that in the zoological nomenclature, can be violated in exceptional cases and only by decision of the pertinent Stratigraphic Committee, when this principle comes into conflict with the name stability requirement and its application may lead to confusion.

None of the listed stratotype properties should characterize the procedure, which was inadequately termed by Meyen (1989), Ruzhentsev (1977), and other researchers as standardization of a reference section; moreover, they contraindict this procedure. In this case, the pertinent section should be termed the *entitative stratigraphic standard* though, in fact, corresponding to the notion of reference section (Librovich and Ovechkin, 1963; *Stratigraficheskii ...*, 1992). Actually, it should be the most suitable (in the exposure degree and completeness of correlation properties) section (or several sections), which is (are) used by stratigraphers to illustrate their conception of the stratigraphic unit. It means that the entitative stratigraphic standard (reference section) fulfils a special reference function to illustrate the stratigraphic unit properties. This (these) is (are) useful and necessary also because of the fact that it is impossible to study all the sections in similar detail (Meyen, 1989). One important correction should be introduced into the notion of the reference section in the sense of Librovich and Ovechkin (1963, p. 21): I cannot agree that reference sections should, among other things, correspond to "some large subdivision of a global scale (stage or larger), or to the largest regional stratigraphic subdivision (usually group, sometimes, rock complex) first established in the other region or country." This requirement seems absolutely unnecessary in the context of an exclusively entitative interpretation of the reference section notion. Moreover, in such an interpretation, reference sections for the same stratigraphic units can be suggested not only by the author of the unit but by any researchers who may have their own dissenting conception of the particular stratigraphic unit and who work with good, well-studied sections (exactly they are the reference sections) but not necessarily with those used by the author of the unit to illustrate his conception. The entitative aspect is not subjected to authorization and regulation in the reference sections (similar to stratotypes), which themselves are analogues of originals (but not of the holo-, lecto-, or neotype!) that illustrate a new conception of the taxon by the revision of biological taxa; i.e., they relate exclusively to the entitative, not the nomenclature aspects of the problem. From the entitative nature of standard reference sections (=reference sections), it transpires that they differ from stratotypes in another feature as well: the time range of the entitative stratigraphic standard should in principle be of the same hierarchical level as the corresponding stratigraphic unit. For a similar reason, both the priority principle and the uniqueness principle are inapplicable to the entitative straigraphic standard. That is why the terms "reference sections" and "entitative stratigraphic standard" are very flimsy. The number of entitative stratigraphic standards (=reference sections) can be as large as necessary to illustrate the properties of the stratigraphic unit as completely as possible. Nonetheless, the nomenclature type (stratotype) should be the only one because only this uniqueness will allow the stratotype to successfully stabilize the name.

The concept itself that is suggested by this or that author concerning the pertinent stratigraphic unit can be termed, by analogy with biology, the *stratoarchetype*. However, there is a difference between a changeable archetype (and stratoarchetype) of the taxon (stratigraphic unit) and a generalized conception of the taxon (stratigraphic unit) shared by the researcher at the moment. Both of them correspond to the notion of archetype (stratoarchetype). However, in the second case concerning the momentary conception of taxon (stratigraphic unit), it would be better, from my viewpoint, to speak about diagnosis (particular substantiation), as it is usually done, rather than about archetype. The above-mentioned difference between the stratigraphic unit and its boundary, which is under study, results from the fact that the stratigraphic unit has both the archetype (all the potentially possible content) and diagnosis (momentary substantiation), whereas the boundary is characterized only by diagnosis. Features of the changeable diagnosis of the boundary are abstracted from the endless characteristics of corresponding contiguous stratigraphic units. Thus, the boundary in stratigraphy is similar to the difference between diagnoses of taxa in biology. The notion of the "stratoarchetype" would include a narrower notion of the "biochronotype" (Ruzhentsev, 1977). Though the

[3] Perhaps, typification of units of the rank lower than the stage should be transposed in the particular region—the stage prototype. Otherwise, the physical basis, which sustains the whole nomenclature superstructure, will disappear.

biostratigraphic method is actually the main one for the Phanerozoic, it would be wrong to reduce all the possibilities and perspectives to biostratigraphy alone. The term "chronotype" (Khalfin, 1973, 1980), while sounding much like the above-mentioned one, means quite a different thing. According to Khalfin, only stratotypes of regional subdivisions supposedly can possess an entitative basis as opposed to stratotypes of the global scale. Therefore, he suggested for these latter the term "chronotype," which "gives us only biochronologic (age) marks of its lower and upper boundaries marked by a replacement of certain organic forms by others" (Khalfin, 1980, p. 171). Although close in meaning, Khafin's term differs from the term "boundary stratotype" in its biostratigraphic accentuation. In the entitative aspect, the notions and terms "chronotype" and "boundary stratotype" are excessive. The conceptual (or biogeosystem) nature of correlative boundaries (as well as correlative stratigraphic units) cannot in principle be reflected and fixed in a single section. Moreover, legalization and regulation of the boundary as a point in the particular section means, in essence, its transposition to the conventional standard (approved point in the time scale), which becomes radically independent of the evolving concepts. That is why the remark of adherents of the "golden spike," who assume that its location in the section can be changed in the future, is naturally under suspicion. In this connection, it would be better to tear off the meaning of the appropriate term "boundary stratotype" from chronostratigraphy, i.e., to treat it as a conventionally accepted, but quite distinct phenomenon (for instance, the zone base), according to which the stratigraphic boundary is defined for a pragmatic purpose, rather than as an entitative stratigraphic standard with the legalized boundary (point).

The term "stratoarchetype" would more adequately reflect the essence of the problem and continue the tradition in stratigraphic terminology, which uses analogous biologic terms. However, it is much more important for stratigraphers to recognize, finally, the fact that biologists recognized long time ago: one section (specimen, type species) is not necessarily the best, however it is obligatory to have one section (specimen, type species) for stabilization and regulation of stratigraphic unit (taxon) name and, thus, it should be legalized. As for the conception (diagnosis) of the stratigraphic unit, the initially indicated type section can, at best, reflect the original, author's conception of the stratigraphic unit. However, it cannot bear in principle all the correlation potentials of the unit (just as one specimen cannot reflect all the properties of a species). The nomenclature type (stratotype) and related priority principle have nothing to do with changeable properties of the stratigraphic unit and boundary selection. The stratotype, as such, should represent one of the coordinated units of corresponding subdivision. An example of the Danian Stage, cited by Krasilov (1977) is inaccurate. Krasilov wrote that if the Danian Stage were the type of the Cretaceous System, its transposition to the Paleogene "would mean the abolishment of the name "Cretaceous System." The inaccuracy here consists in the fact that the name "Cretaceous System" appeared in 1831 whereas that of the Paleogene in 1872. In this case, the name of the combined subdivision (Danian Stage + Paleogene) would be named the "Cretaceous System," which would create a great inconvenience (distortion of stability, confusion of names). That is why the solution of similar problems in biology is a prerogative of the International Commission. However, similar situations in stratigraphy, as in biology, would be relatively rare. There is little likelihood that the Danian Stage would be indicated as the type of the Cretaceous System.

It is also important to understand the following: the characterization and content of a stratigraphic unit (as in the case with taxon) in principle should not be subjected to any legalization and regulation, including the reference to any section. These references can be exclusively of the illustrative character. Taking into account the specifics of stratigraphy, one can accept only legalization of the stratigraphic unit boundary (I mean the conceptual, correlative boundary, not the point in the time scale).

I am compelled again and again to discuss from different standpoints these, at first glance, not very complicated problems, which were difficult to overcome even for such a brilliant theorist as Meyen. Though Meyen differentiated the procedures of typification and standardization, he related hypostratotypes that compensate for stratotype incompleteness to the procedure of typification, not standardization of reference sections. First, the analogy of hypostratotypes with typoids in biology is invalid here because the latter are one rank lower than the pertinent taxon (even their sum does not represent a species). Second, it is doubtful that the typoid in biology "typifies rather than standardizes features" (Meyen, 1989, p. 79). I believe that the uniqueness of the specimen that keeps the species name remains stable. I also cannot accept Meyen's conclusion that it is impossible to discard standardization of reference sections because "Main (Stenon's and Hecksley's) principles of stratigraphy and the principle of chronologic interchangeability of features... require the substratum, or initial sections, which can always be revisited to reexamine the correctness in application of all three principles" (Meyen, 1989, p. 81). This is substantiated by the following model example. Let us imagine that the succession of complexes A–B–C is accepted as a basis for correlation. Let us also assume that, in the particular section, we observe the succession A–C–B. If the last succession is true, then, according to the Hecksley principle, the universal scale takes the form A–(B + C). Everything is correct in this model with one exception: the standard reference section has nothing to do with this situation. Regardless of the section in which a distortion of the previously accepted succession is observed, the scale will acquire the form A–(B + C). The single section can never possess all the

properties of the stratigraphic unit; such sections always perform a reference, illustrative function. That is why the term "entitative stratigraphic standard" seems, from my point of view, very confusing. I would replace the wording "it is impossible to discard standardization of reference sections" with the wording "it is impossible to discard the indication of reference sections," which, however, is quite evident.

It is interesting that at the first stage of the development of typification in biology, when the population concept had not yet won, it also suffered from similar problems. Perhaps many taxonomists would be astonished after acquainting themselves with the situation in zoological nomenclature a mere 60–70 years ago when the holotype (in addition to its nomenclature type status) was required to represent, when possible, "...all the features of the new species or subspecies in their most typical form..." (*Pravila* ..., 1932, p. 25). No traces of such requirements are present in current codes of zoological nomenclature (*Mezhdunarodnyi* ..., 1966, 1988). In the code preamble, it is clearly stated that the code is aimed at providing stability and universality of scientific names; none of the statements and recommendations of the code restrict the freedom of thought or action in taxonomy. Rasnitsyn (1992) paid attention to the inaccuracy of this statement and formulated three clear, taxonomically dependent principles of modern nomenclature concerning its entitative aspect: the principle of the type, the principle of hierarchy, and the principle of synonymy. In fact, all of them are consequences of the hierarchical structure of the system; i.e., one can state that nomenclature regulations in the modern International Code of Zoological Nomenclature (ICZN) are oriented to the hierarchical system. Strictly speaking, the entitative aspect of the modern ICZN is limited by hierarchy, which is incomparable, for instance, with the latest edition of the Russian stratigraphic code. Figuratively speaking, biology easily overcame an illness that acquired chronic form in stratigraphy.

The second abnormality in stratigraphic typification is closely connected with the first one and consists in the fact that hierarchy in classification is not accompanied by hierarchy in typification. Whereas in biological classification, one of the coordinated taxa serves as a type, in stratigraphy, the role of classification type is played by one of the elements of the same taxonomic rank. Probably only P. Silvestor-Bradley (cited after Schindewolf, 1975) and Krasilov (1977) noted this abnormal peculiarity of typification in stratigraphy. In stratigraphy, typification of such kind results in a considerable widening of nomenclature limits in comparison with those in biological classification where the type is always represented by a taxon of the lower rank. It is not difficult to surmise the reason for this unusual typification: the stratotype in stratigraphy also performs the entitative function. However, the wide nomenclature frame in stratigraphy always remains generally insufficient to hold all the properties of the stratigraphic unit. By analogy with organismocentrism in biology, this approach could be named "stratocentrism." The analogy with biology is evident: none of the sections, no matter how perfect it is, can completely and forever reflect the conception of a stratigraphic unit. The search for the ideal section (stratotype), which would combine both nomenclature and entitative aspects of a stratigraphic unit, resembles, in fact, the search for the philosopher's stone. Indeed, intense investigations even in an erroneous direction can also bring positive results. However, just as the discovery of ammonium chloride and phosphorus does not justify the basic idea of alchemists, so comprehensive studies of selected sections (stratotype competitions), being useful in themselves, do not justify the modern concept of stratotypes.

Thus, an unfeasible longing to combine the nomenclatural and entitative aspects in a single section (stratotype) resulted in the shelving of the hierarchy principle in stratigraphic typification. This, in turn, transformed the priority principle into an obstacle to the perfection of stratigraphic classification. Let us compare, for instance, paragraph XII.9 of the new Russian Stratigraphic Code (*Stratigraficheskii* ..., 1992) with corresponding statements in biological nomenclature. When subdividing taxons (the most routine procedure in taxonomy), the former name remains valid for the group that hosted the taxon type. This is convenient and reasonable. The similar procedure in stratigraphy requires, in accordance with the above-mentioned paragraph, abandoning the old and creating two or three new names, which would appear absurd in biological classification. In this respect, the next paragraph XII.10, according to which the name of the stratigraphic unit can be retained when its range changes and when the change concerns no more than one third of the range does not look any better.

One peculiarity of stratigraphy, which hinders, at first glance, the application of the hierarchy principle in stratigraphic typification, is that, contrary to biologic classification, where the last (lowest) member of hierarchy (specimen) is indivisible, any smallest stratigraphic subdivision lacks this property. This specific feature does not concern units of the global scale. In the latter, the name of the lowest-rank unit (chronozone) is based, as in biology, on the holotype; i.e., formally it does not require the material carrier of the name in the form of a certain stratigraphic unit. However, any unit of the lowest rank from the regional and local scales actually does not possess the property of indivisibility, and this represents a serious objection to introducing hierarchy into their typification. The approach suggested in the above-mentioned paragraphs XII.9 and XII.10 of the Stratigraphic Code (*Stratigraficheskii* ..., 1992) can be used when considering precisely these (and only these!) lowest hierarchical members of regional and local units (member, bed). The probability that new boundary will separate, when dividing the formation into parts, more than one third of the type bed is

less than the probability that it will separate more than one third of the whole formation, and therefore means that old names will rarely be rejected.

The peculiarities of nomenclatural procedures brought us to the dilemma: to continue using the "ancestors' language" and, thus, to slow and even interrupt the development of the entitative aspect of stratigraphic classification, or to abandon it and construct a progressively developing entitative stratigraphic classification. This conclusion can also be found in the paper of Zubakov (1992), the authoritative Russian stratigrapher. Leaving aside one of the eternal questions of the Russian intellectuals: "Who is to blame?," Zubakov restricted himself to another traditional question: "What is to be done?" He proposed to treat the chronostratigraphic (international) scale without its further revision as a historically elaborated construction performing mainly a linguistic function and guarded by the priority principle, and to develop the entitative aspect in the scope of another, parallel stratigraphy, "nomostratigraphy" in his terminology, free of priority constraints. However, if we preserve the existing system of typification, then, sooner or later, any new stratigraphy will find itself under the load of new priorities, which will decelerate the development of its entitative substratum. That is why I consider another way to be more reasonable and suggest to change the typification system in stratigraphy using, as an example, the more "civilized" biologic typification. In this case, the "insidious" question that Zhamoida asked (1980, p. 36) after the publication of the book by Krasilov (1977): "If typification requires the nomenclatural type, then why is precisely the stratotype section unable to satisfy this requirement?" will become irrelevant.

Both aspects of typification discussed above and their contraposition are meaningful only when we consider stratigraphic units and their classification as a reflection of certain real processes and events that occurred during the Earth's history. However, if we accept the concept of the conventional nature of stratigraphic units and stratigraphic classification, then typification in stratigraphy will automatically be deprived of its entitative aspect (that is good in itself) and pass into the purely technical field comparable with standardization in the industry. In such a system of notions, the terms "standard scale," "standard boundary," and "standard section" are quite appropriate, and a stratotype acquires the function of a universal standard of the geochronologic scale (Hedberg, 1978). It would be better to term the typification of conventional objects and units as standardization. The main characteristic of typification of this kind is its lack of any claim to service not only the entitative aspect but also the nomenclatural aspect. Indeed, in stratigraphy, these standards of time intervals are introduced to fill (without gaps and overlapping) the time scale with a system of historically elaborated (traditional) names rather than to stabilize the corresponding names. The logic of this procedure implies the abandonment of interval-stratotypes and turns its full attention to the boundary-stratotypes (points in the time scale).

In general, standardization represents the most precise and logically most irreproachable replication of the chronostratigraphic concept in the process of typification. This makes it advantageous as compared with traditional typification based on its entitative aspect. Perhaps, I may risk to draw the analogy between chronostratigraphy (together with standardization) in stratigraphy and cladistics in biology. In both cases, the logic of actions is the least vulnerable but the initial postulates are erroneous because in the former case, the concept of abstract monotonous time is used, whereas in the latter, evolution is assumed to proceed by the most efficient way. In both cases, the difference rank is, in fact, ignored.

Thus, typification in stratigraphy is considered in a very broad sense and includes three different procedures: (1) typification *sensu stricto*, which is concerned exclusively with the nomenclatural aspect; (2) legalization of the entitative aspect of the stratigraphic unit; and (3) standardization when the stratotype becomes the conventional standard for the time interval. It is important to note that standardization is the logical consequence of the entitative aspect's legalization: limits of the accredited type cannot fit the inevitably changeable content for long; therefore, they turn into conventional points of (absolute) time independent of the evolving content. Such a drift toward conventionalism explains the refusal of the most consistent advocates of chronostratigraphy to consider the stratigraphic scale as a scale of entitative classification. Unfortunately, not all stratigraphers recognize this, as is evident, for instance, from the first and second paragraphs of item III.1 of the Russian Stratigraphic Code (*Stratigraficheskii* ..., 1992), which essentially contradict each other. To the point, two Russian terms "*etalon*" and "*standart*" are expressed in English by only the one term "standard."

ANALOGY WITH BIOLOGIC CLASSIFICATION

The previous discussion is saturated with analogies that mainly relate to typification problems. The table presents additional analogies of some entitative aspects of classification in both sciences. These analogies form the basis for the analysis of both similar and specific elements in these sciences.

The analogies cited in the table can be continued. For instance, one can note some similarity in methodology; the analogy between cladistics and the chronological concept was already mentioned. There is also a certain analogy between the hypothesis of discrete equilibrium and that of discrete, agradation cycles (Goodvin and Anderson, 1985) and between the phenetic approach without assessment of features and age determination based on chronovalency and chronopotentials (Pop, 1971). I take the risk of drawing one more analogy between concepts of both classifications. In the

properties of the stratigraphic unit; such sections always perform a reference, illustrative function. That is why the term "entitative stratigraphic standard" seems, from my point of view, very confusing. I would replace the wording "it is impossible to discard standardization of reference sections" with the wording "it is impossible to discard the indication of reference sections," which, however, is quite evident.

It is interesting that at the first stage of the development of typification in biology, when the population concept had not yet won, it also suffered from similar problems. Perhaps many taxonomists would be astonished after acquainting themselves with the situation in zoological nomenclature a mere 60–70 years ago when the holotype (in addition to its nomenclature type status) was required to represent, when possible, "...all the features of the new species or subspecies in their most typical form..." (*Pravila* ..., 1932, p. 25). No traces of such requirements are present in current codes of zoological nomenclature (*Mezhdunarodnyi* ..., 1966, 1988). In the code preamble, it is clearly stated that the code is aimed at providing stability and universality of scientific names; none of the statements and recommendations of the code restrict the freedom of thought or action in taxonomy. Rasnitsyn (1992) paid attention to the inaccuracy of this statement and formulated three clear, taxonomically dependent principles of modern nomenclature concerning its entitative aspect: the principle of the type, the principle of hierarchy, and the principle of synonymy. In fact, all of them are consequences of the hierarchical structure of the system; i.e., one can state that nomenclature regulations in the modern International Code of Zoological Nomenclature (ICZN) are oriented to the hierarchical system. Strictly speaking, the entitative aspect of the modern ICZN is limited by hierarchy, which is incomparable, for instance, with the latest edition of the Russian stratigraphic code. Figuratively speaking, biology easily overcame an illness that acquired chronic form in stratigraphy.

The second abnormality in stratigraphic typification is closely connected with the first one and consists in the fact that hierarchy in classification is not accompanied by hierarchy in typification. Whereas in biological classification, one of the coordinated taxa serves as a type, in stratigraphy, the role of classification type is played by one of the elements of the same taxonomic rank. Probably only P. Silvestor-Bradley (cited after Schindewolf, 1975) and Krasilov (1977) noted this abnormal peculiarity of typification in stratigraphy. In stratigraphy, typification of such kind results in a considerable widening of nomenclature limits in comparison with those in biological classification where the type is always represented by a taxon of the lower rank. It is not difficult to surmise the reason for this unusual typification: the stratotype in stratigraphy also performs the entitative function. However, the wide nomenclature frame in stratigraphy always remains generally insufficient to hold all the properties of the stratigraphic unit. By analogy with organismocentrism in biology, this approach could be named "stratocentrism." The analogy with biology is evident: none of the sections, no matter how perfect it is, can completely and forever reflect the conception of a stratigraphic unit. The search for the ideal section (stratotype), which would combine both nomenclature and entitative aspects of a stratigraphic unit, resembles, in fact, the search for the philosopher's stone. Indeed, intense investigations even in an erroneous direction can also bring positive results. However, just as the discovery of ammonium chloride and phosphorus does not justify the basic idea of alchemists, so comprehensive studies of selected sections (stratotype competitions), being useful in themselves, do not justify the modern concept of stratotypes.

Thus, an unfeasible longing to combine the nomenclatural and entitative aspects in a single section (stratotype) resulted in the shelving of the hierarchy principle in stratigraphic typification. This, in turn, transformed the priority principle into an obstacle to the perfection of stratigraphic classification. Let us compare, for instance, paragraph XII.9 of the new Russian Stratigraphic Code (*Stratigraficheskii* ..., 1992) with corresponding statements in biological nomenclature. When subdividing taxons (the most routine procedure in taxonomy), the former name remains valid for the group that hosted the taxon type. This is convenient and reasonable. The similar procedure in stratigraphy requires, in accordance with the above-mentioned paragraph, abandoning the old and creating two or three new names, which would appear absurd in biological classification. In this respect, the next paragraph XII.10, according to which the name of the stratigraphic unit can be retained when its range changes and when the change concerns no more than one third of the range does not look any better.

One peculiarity of stratigraphy, which hinders, at first glance, the application of the hierarchy principle in stratigraphic typification, is that, contrary to biologic classification, where the last (lowest) member of hierarchy (specimen) is indivisible, any smallest stratigraphic subdivision lacks this property. This specific feature does not concern units of the global scale. In the latter, the name of the lowest-rank unit (chronozone) is based, as in biology, on the holotype; i.e., formally it does not require the material carrier of the name in the form of a certain stratigraphic unit. However, any unit of the lowest rank from the regional and local scales actually does not possess the property of indivisibility, and this represents a serious objection to introducing hierarchy into their typification. The approach suggested in the above-mentioned paragraphs XII.9 and XII.10 of the Stratigraphic Code (*Stratigraficheskii* ..., 1992) can be used when considering precisely these (and only these!) lowest hierarchical members of regional and local units (member, bed). The probability that new boundary will separate, when dividing the formation into parts, more than one third of the type bed is

less than the probability that it will separate more than one third of the whole formation, and therefore means that old names will rarely be rejected.

The peculiarities of nomenclatural procedures brought us to the dilemma: to continue using the "ancestors' language" and, thus, to slow and even interrupt the development of the entitative aspect of stratigraphic classification, or to abandon it and construct a progressively developing entitative stratigraphic classification. This conclusion can also be found in the paper of Zubakov (1992), the authoritative Russian stratigrapher. Leaving aside one of the eternal questions of the Russian intellectuals: "Who is to blame?," Zubakov restricted himself to another traditional question: "What is to be done?" He proposed to treat the chronostratigraphic (international) scale without its further revision as a historically elaborated construction performing mainly a linguistic function and guarded by the priority principle, and to develop the entitative aspect in the scope of another, parallel stratigraphy, "nomostratigraphy" in his terminology, free of priority constraints. However, if we preserve the existing system of typification, then, sooner or later, any new stratigraphy will find itself under the load of new priorities, which will decelerate the development of its entitative substratum. That is why I consider another way to be more reasonable and suggest to change the typification system in stratigraphy using, as an example, the more "civilized" biologic typification. In this case, the "insidious" question that Zhamoida asked (1980, p. 36) after the publication of the book by Krasilov (1977): "If typification requires the nomenclatural type, then why is precisely the stratotype section unable to satisfy this requirement?" will become irrelevant.

Both aspects of typification discussed above and their contraposition are meaningful only when we consider stratigraphic units and their classification as a reflection of certain real processes and events that occurred during the Earth's history. However, if we accept the concept of the conventional nature of stratigraphic units and stratigraphic classification, then typification in stratigraphy will automatically be deprived of its entitative aspect (that is good in itself) and pass into the purely technical field comparable with standardization in the industry. In such a system of notions, the terms "standard scale," "standard boundary," and "standard section" are quite appropriate, and a stratotype acquires the function of a universal standard of the geochronologic scale (Hedberg, 1978). It would be better to term the typification of conventional objects and units as standardization. The main characteristic of typification of this kind is its lack of any claim to service not only the entitative aspect but also the nomenclatural aspect. Indeed, in stratigraphy, these standards of time intervals are introduced to fill (without gaps and overlapping) the time scale with a system of historically elaborated (traditional) names rather than to stabilize the corresponding names. The logic of this procedure implies the abandonment of interval-stratotypes and turns its full attention to the boundary-stratotypes (points in the time scale).

In general, standardization represents the most precise and logically most irreproachable replication of the chronostratigraphic concept in the process of typification. This makes it advantageous as compared with traditional typification based on its entitative aspect. Perhaps, I may risk to draw the analogy between chronostratigraphy (together with standardization) in stratigraphy and cladistics in biology. In both cases, the logic of actions is the least vulnerable but the initial postulates are erroneous because in the former case, the concept of abstract monotonous time is used, whereas in the latter, evolution is assumed to proceed by the most efficient way. In both cases, the difference rank is, in fact, ignored.

Thus, typification in stratigraphy is considered in a very broad sense and includes three different procedures: (1) typification *sensu stricto*, which is concerned exclusively with the nomenclatural aspect; (2) legalization of the entitative aspect of the stratigraphic unit; and (3) standardization when the stratotype becomes the conventional standard for the time interval. It is important to note that standardization is the logical consequence of the entitative aspect's legalization: limits of the accredited type cannot fit the inevitably changeable content for long; therefore, they turn into conventional points of (absolute) time independent of the evolving content. Such a drift toward conventionalism explains the refusal of the most consistent advocates of chronostratigraphy to consider the stratigraphic scale as a scale of entitative classification. Unfortunately, not all stratigraphers recognize this, as is evident, for instance, from the first and second paragraphs of item III.1 of the Russian Stratigraphic Code (*Stratigraficheskii* ..., 1992), which essentially contradict each other. To the point, two Russian terms "*etalon*" and "*standart*" are expressed in English by only the one term "standard."

ANALOGY WITH BIOLOGIC CLASSIFICATION

The previous discussion is saturated with analogies that mainly relate to typification problems. The table presents additional analogies of some entitative aspects of classification in both sciences. These analogies form the basis for the analysis of both similar and specific elements in these sciences.

The analogies cited in the table can be continued. For instance, one can note some similarity in methodology; the analogy between cladistics and the chronological concept was already mentioned. There is also a certain analogy between the hypothesis of discrete equilibrium and that of discrete, agradation cycles (Goodvin and Anderson, 1985) and between the phenetic approach without assessment of features and age determination based on chronovalency and chronopotentials (Pop, 1971). I take the risk of drawing one more analogy between concepts of both classifications. In the

Analogies in zoological and stratigraphic classifications

Item of analogy	Zoological classification	Stratigraphic classification	
Objects	Taxons	Stratigraphic units	
Main content (quintessence)	Relationship (similarity–dissimilarity)	Time succession, time (geological)	
Meronomic correspondence	Homologization	Correlation	
Potential content (object characteristics)	Archetype	Stratoarchetype	Stratotype, boundary stratotype in current meaning
Current conceptual difference (substantiation) of the object	Diagnosis	Diagnosis of stratigraphic unit, boundary substantiation	
Nomenclature type of the object	Holotype, type species, type genus	Stratotype, boundary stratotype (when proper name is present)	
Hierarchical units	a) Species, genus, family, etc.	a) Zone (correlative), stage, period, etc.	
	b) Parataxons	b) Bed, member, formation etc.	
Main levels of hierarchy	a) Species level	a) Registration units	
	b) High taxa level	b) Correlative units	

case of causal stratigraphy, the procedure for the assessment of the stratigraphic unit rank and the assessment and selection of a boundary are preceded by certain historical–geological reconstructions (Krasilov, 1977; Meyen, 1989). In biology, similar methodological procedures (phylogenetic reconstructions) are accomplished so far only in cladistics. I believe, however, that traditional (evolutionary) systematization should also follow this requirement (Lazarev, 1993).

TOTALITARIANISM IN STRATIGRAPHY?

The question mark in the title of the section expresses not so much my doubts that totalitarianism in stratigraphy is justified and should be preserved but rather my doubts in the validity of the analogy itself. The analogy to developments in the social sphere distorted my initial intention to restrict myself to analogies with biology, because biology, as well as other sciences, lack similar phenomenon. Science is in itself democratic.[4] Such examples as the fight of church against heliocentrism or the fight against cybernetics and genetics in the former USSR are social phenomena that were imposed upon science from outside. It is quite a different situation in stratigraphy where totalitarianism appeared without social pressure and until now has not been recognized by stratigraphers just as the majority of Soviet people did not recognize before perestroika that they lived in a totalitarian state. As far as I know, only Meyen (1985, 1989) noted the fact that official decisions in stratigraphy concern entitative problems, but he said little about the causes of such an unusual situation in stratigraphic science. It is understandable that operating geological teams dealing, for instance, with geological mapping need in any particular case a certain regulation that is collectively elaborated and approved. Regulation of such kind is unavoidable and is present in different fields of human activity. I see elements of totalitarianism in another point, in the legalization and regulation of entitative scientific conceptions even though they are approved by an authoritative group of scientists. I am sure that a document such as a code should not contain the system of scientific classification or definitions of any entitative notions such as stage, zone, stratotype and others. In connection with this, A.S. Rautian called my attention to the fact that in biology (contrary to stratigraphy), we have codes of zoological nomenclature, not codes of zoology or botany as a whole. Only in stratigraphy is it considered normal to make collective decisions on entitative notions. These decisions then acquire an official status in the stratigraphic codes of various countries. As a result, we have such strict regulation, for instance, for a zone of global scale, as: "The zone must have a stratotype" (*Stratigraficheskii* ..., 1992, p. 28). In fact, this juridical regulation means that Russian stratigraphers should follow a dubious typification system even though not all chronostratigraphers share this view relative to the zone. We should be happy that we at least have the possibility to think differently and even publish our concepts in opposition to those adopted in the codes (totalitarianism in science is, fortunately, weaker than in society). Nevertheless, it is apparent how collectively approved entitative notions have been imposed on stratigraphers. In addition, collective decisions on entitative notions usually bear many fundamental contradictions, which is clearly demonstrated by both editions of the stratigraphic codes of the USSR (Russia). In this connection, I agree with Zubakov's critique of the second edition of the Russian Stratigraphic Code (Zubakov, 1992) and could continue the list of contradictions related to typification problems.

[4] In connection with this, let us recall Popper (1983), who believed that science, in addition to its applied value, is even more valuable because of its liberating influence as one of the greatest forces for human freedom.

What is the cause of totalitarianism in stratigraphy? I think that this phenomenon may be explained, first, by the victory of the stratigraphy concept, which makes a fetish of conventionality and standardization of stratigraphic units and their boundaries, and, thus, considers collective decisions to be infallible. According to this concept, only local scales are of a natural character, whereas the global scale is viewed as an arbitrary standard. The typification system, which promises the coming bright chronostratigraphic future, when all boundaries of the global scale are legalized and regulated, also developed in line with this concept. This suggests that old names can be retained by redecorating the modern global scale rather than by introducing hierarchical coordination into the typification system. It means only that the position of boundaries should be somewhat refined and then legalized; the intervals between these boundaries will preserve the nomenclature and entitative aspects of stratigraphic units at the moment of their legalization.

Totalitarianism in stratigraphy is also caused, probably, by its own inherent tendency toward convention. The point is that boundaries between stratigraphic units should be, for pragmatic reasons, as distinct as possible, in contrast to biology where indistinct boundaries between taxons can sometimes be accepted. Therefore, when selecting the boundary, convention is unavoidable at least until such time when some common methodical solution to this problem is found.

Indeed, it is difficult to object to the requirement for stability in general. In this case, it is necessary to discriminate between (1) stability in names, (2) stability in boundary positions, and (3) stability in the available hierarchy of boundaries and stratigraphic units of a global scale. Stability in names can be preserved during any perturbations of entitative aspect if we accept the typification principles that are successfully used in biology. However, legalization of the content and hierarchy of stratigraphic units of the modern global scale is equivalent to the encouragement of totalitarianism in stratigraphy. On the one hand, we are lucky that the requirement to legalize the entitative aspect of stratigraphic units was formed only in the last few decades; otherwise many customary names (for instance, Cambrian, Silurian, Carboniferous, Permian) would have been rejected long ago, because the range (and, accordingly, the content) of these units significantly changed. On the other hand, it is surprising that many recent stratigraphers believe that the main work is already done and very soon we will arrive at the bright future and obtain the final universal scale (only the boundaries remain to be defined). A similar approach in biology, where systematization also fulfils a function of international language, would mean the following: it is high time to stop entitative revision of systems, to conclusively refine present-day boundaries between taxons, and to legalize them in order to reach a harmony of opinions. Such a suggestion would mean the cessation in the development of classification (any classification); therefore the requirement of stability is applicable only to names.

CONCLUSION

The foundation of the current chronostratigraphic paradigm was already laid in the first versions of a global scale by introducing into stratigraphy two parallel systems of units: a stratigraphic and a geochronologic one. There is, however, a fundamental difference between geochronologic and chronostratigraphic units. Whereas the former are no more than the adequate temporal aspect of stratigraphic units, the latter acquired a quite independent status.

The chronostratigraphic concept is related to the particularly pragmatic (instrumental) approach in stratigraphy and aimed at a quick elaboration of the ultimate model of a universal scale with the time axis divided by points, i.e., by standards of lower boundaries of stratigraphic units. In the long run, this approach will logically lead to the rejection of typification of stratigraphic units and to a concern about typification of boundaries (points). In this case, the nomenclature aspect of typification is excluded, and the development of the entitative aspect of the global scale will become unnecessary when all the points are established and accredited. It means that links between stratigraphic scales, on the one hand, and between problems of periodization and hierarchy of historical–geological processes, on the other, will, consciously or unconsciously, be broken.

One can suggest that the long-term domination of the pragmatic approach in stratigraphy is explained to a large extent by its striving to define boundaries with the greatest possible accuracy. Taking into consideration the vagueness of correlative boundaries, one is forced to have recourse to a conventional approach when selecting the most appropriate boundary. However, it is important to recognize the specific feature of conventional decisions characteristic of the chronostratigraphic approach: conditional points in the time scale become in principle the ultimate basis of the scale in the sense that they do not require revision in the context of this concept.

It is hardly probable that another, "purely scientific" direction in stratigraphy represented by such names as Schindewolf, Meyen, Krasilov, and Zubakov will cease to exist when all boundaries are legalized. As early as a quarter of a century ago, Sokolov wrote that the unguided striving toward a "revision of the common West European standard that is actually given to us by history" brings the threat to stratigraphic stability (Sokolov, 1971, p. 164).

It is unreasonable to object to stability in general, particularly the stability of stratigraphic scales, which form the basis for geological mapping. Stability, like convention, needs to be considered differentially. The stability that relates to the entitative aspect is admissi-

ble in stratigraphy as a conscious but temporal conservation of currently prevailing notions. It means that the hierarchy of stratigraphic units and the position of boundaries in the global scale must be changed not gradually and independently of the general strategy of the stratigraphic scale construction, but in a stage-by-stage, jumpwise manner, when old conceptions of stratigraphic classification die off. Of course, the "maturity" of new conceptions is a subjective matter; therefore, conservatism (stability) by all means will be maintained by collective decisions. It is important, however, to avoid the absolute stability (and, accordingly, convention) that is determined by the chronostratigraphic paradigm. Only the requirement of name stability is unconditionally admissible. The typification procedure corresponding to this requirement should be of the greatest efficiency and independent of entitative problems.

The recognition of the right to revise the entitative aspect of stratigraphic scales makes the problem of name stability crucial. The current system of name typification is maladjusted for work on the entitative revision of stratigraphic scales, because in the absence of hierarchy in typification, the priority principle does not allow the old name to be preserved when the position of the stratigraphic unit boundary significantly changes. Typification similar to that in biology would provide stronger stability of names despite any perturbation in stratigraphic scales. The essential basis of all stratigraphic codes is of such a nature that it cannot regulate problems of a strict selection of names; all problems are commonly solved based on intrigues, personal relations, and, eventually, on voting. Only essential changes in the typification procedure can provide the basis for the creation of real jurisdiction, i.e., for elaboration of the international code of stratigraphic nomenclature. It is important to emphasize that reorganization of the typification procedure in itself will never affect existing names and adopted boundaries of stratigraphic units of both global and regional scales. To accept the necessity of changes in the typification procedures, stratigraphers need, first, to recognize that the stratigraphic scale is not only an arbitrary "standard" for time measurements but is also a model reflecting the entitative aspect of historical–geological processes and, second, to reject the current procedure that legalizes the archetype (the entitative aspect of the stratigraphic unit) in the stratotype.

ACKNOWLEDGMENTS

I thank Dr. M. Bassett (National Museum of Wells, Cardiff) for discussions that led me to write this paper. Initially, his coauthorship was suggested; however, this intention was never realized for several reasons. Therefore, he is not responsible for the content.

I cannot list all the persons who discussed different aspects of this work. In this connection, I wish to mention the particularly constructive discussions with A.Yu. Rozanov and A.S. Alekseev. I am also grateful to A.I. Zhamoida and K.V. Simakov for reviewing the manuscript. It should be noted that principal disagreements between our respective viewpoints remain in force.

Reviewers: A.S. Alekseev, A.Yu. Rozanov, A.I. Zhamoida and K.V. Simakov

REFERENCES

Cowie, J.W., Ziegler, W., Boucot, A.J., Bassett, M.G., and Remane J., Guidelines and Statutes of the International Commission on Stratigraphy (ICS), *CFS, Cour. Forschungsinst. Senckenberg*, 1986, no. 83, pp. 1–14.

Goodvin, P.M. and Anderson, E.J., Punctuated Agradational Cycles: A General Hypothesis of Episodic Stratigraphic Accumulation, *J. Geol.*, 1985, vol. 3, no. 5, pp. 515–533.

Hancock, J.M., The Historic Development of Concepts of Biostratigraphic Correlation, *Concepts and Methods of Biostratigraphy*, Kauffman, E.G. and Hazel, J.E., Eds., Stroudsbourg: Dowden, Hutchison, and Ross, 1977, pp. 3–22.

Hedberg, H.D., Stratotypes and an International Geochronologic Scale, in *Contr. Geol. Time Scale., Int. Geol. Congr. Sidney, 1976*, Tulsa, Okla., 1978, pp. 33–38.

Holland, Ch., Chronostratigraphy and Other Aspects of Stratigraphic Classification, *Izv. Akad. Nauk Kaz. SSR, Ser. Geol.*, 1979, nos. 4–5, pp. 6–11.

Jaeger, H., Trends in stratigraphisher Methodik und Terminologie, *Z. Geol. Wiss.*, 1981, vol. 9, no. 3, pp. 309–332.

Johnson, J.J., Intent and Reality in Biostratigraphic Zonation, *J. Paleontol.*, 1979, vol. 53, pp. 931–942.

Johnson, J.J., Belief and Reality in Biostratigraphic Zonation, *Newsl. Stratigr.*, 1992, vol. 26, no. 1, pp. 41–48.

Karpinsky, A.P., On Ammonoids from the Artinskian Stage and Some Similar Carboniferous Forms, in *Sobranie sochinenii, Tom 1* (Collected Works, vol. 1), Moscow: Akad. Nauk SSSR, 1945, pp. 32–151.

Kestler, A., Spirit in the Machine, *Voprosy Filisofii*, 1993, no. 9, pp. 93–122.

Khalfin, L.L., Phytostratigraphy of the Kuznetsk Basin from the Point of View of General Theoretical Stratigraphy, *Tr. Sib. Nauchno–Issled. Inst. Geol. Geofiz. Miner. Syr'ya*, 1973, vol. 140, part 1, pp. 7–25.

Khalfin, L.L., *Teoreticheskie voprosy stratigrafii* (Theoretical Problems of Stratigraphy), Novosibirsk: Nauka, 1980.

Krasilov, V.A., *Evolyutsiya i biostratigrafiya* (Evolution and Biostratigraphy), Moscow: Nauka, 1977.

Lazarev, S.S., On Methods of Phylogeny, *Paleontol. Zh.*, 1993, no. 2, pp. 5–17.

Librovich, L.S. and Ovechkin, N.K., *Zadachi i pravila izucheniya i opisaniya stratotipov i opornykh stratigraficheskikh razrezov* (Aims and Rules of the Study and Description of Stratotype and Reference Sections), Moscow: Gostoptekhizdat, 1963.

Meyen, S.V., Structure of Theoretical Stratigraphy, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1985, no. 11, pp. 8–16.

Meyen, S.V., *Vvedenie v teoriyu stratigrafii* (Introduction to Theory of Stratigraphy), Moscow: Nauka, 1989.

Mezhdunarodnyi kodeks zoologicheskoi nomenklatury. Vtoroe izdanie (Int. Code of Zoological Nomenclature. Second ed.), Moscow: Nauka, 1966.

Mezhdunarodnyi kodeks zoologicheskoi nomenklatury. Izdanie tret'e (International Code of Zoological Nomenclature. Third Edition), Moscow: Nauka, 1988.

Pop, E.I., Determination des ages geologiques a l'aide des chronovalences et des chronopotentiels, *Bul. Stiinte. Sci. Geol. Repub. Soc. Rom.*, 1971, vol. 13, pp. 73–80.

Popper, K.R., *The Logic of Scientific Discovery*, London: Hutchison, 1980. Translated under the title *Logika i rost nauchnogo znaniya*, Moscow: Progress, 1983.

Pravila paleozoologicheskoi nomenklatury (Rules of Paleozoological Nomenclature), Likharev, B.K., Ed., Leningrad: Gos. Nauch.–Tekhnich. Geol.–Razved., 1932.

Rasnitsyn, A.P., Principles of Nomenclature and Taxon Nature, *Zh. Obshch. Biol.*, 1992, vol. 53, no. 3, pp. 307–313.

Rasnitsyn, A.P. and Dlusskii, G.M., Principles and Methods of Lineage Reconstruction, in *Melovoi biotsenoticheskii krizis i evolyutsiya nasekomykh* (Cretaceous Biocoenotic Crisis and Insect Evolution), Moscow: Nauka, 1988, pp. 5–15.

Ruzhentsev, V.E., Biochronotype or Stratotype?, *Paleontol. Zh.*, 1977, no. 12, pp. 23–34.

Schindewolf, O., *Stratigraphie und Stratotypus*, Mainz: Akad. Wiss. Literatur, 1970. Translated under the title *Stratigrafiya i Stratotipy*, Moscow: Mir, 1975.

Sokolov, B.S., Biochronology and Stratigraphic Boundaries, in *Problemy obshchei i regional'noi geologii* (Problems of Global and Regional Geology), Novosibirsk: Nauka, 1971, pp. 155–178.

Starobogatov, Ya.I., Operating Methods of Systematization and Problem of Species Criterion, *Zool. Zh.*, 1968, vol. 47, no. 6, pp. 875–886.

Stepanov, D.L. and Mesezhnikov, M.S., *Obshchaya stratigrafiya* (General Stratigraphy), Leningrad: Nedra, 1979.

Stratigraficheskii kodeks. Izdanie vtoroe, dopolnennoe (Stratigraphic Code. Second Edition, Supplemented), St. Petersburg: Mezhved. Stratigr. Komitet, 1992.

Zhamoida, A.I., Essence and Relationship of Main Stratigraphic Units, in *Stratigraficheskaya klassifikatsiya* (Stratigraphic Classification), Leningrad: Nauka, 1980.

Zhamoida, A.I., Kovalevskii, O.P., and Moiseeva, A.I., *Obzor zarubezhnykh stratigraficheskikh kodeksov* (Review of Foreign Stratigraphic Codes), Moscow: Nauka, 1969.

Zubakov, V.A., *Ritmostratigraficheskie podrazdeleniya. Proekt dopolnenii k Stratigraficheskomu kodeksu SSSR* (Rhythmostratigraphic Units. Draft of Supplements to the Stratigraphic Code of the USSR), Leningrad: Vses. Geol Inst. (VSEGEI), 1978.

Zubakov, V.A., On Complete Stratigraphic Classification, in *Stratigraficheskaya klassifikatsiya* (Stratigraphic Classification), Leningrad: Nauka, 1980, pp. 90–115.

Zubakov, V.A., A New Approach to Stratigraphic Classification, *Sov. Geol.*, 1992, no. 5, pp. 46–53.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 198–199. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 105–106.
Original Russian Text Copyright © 1997 by Zhamoida.
English Translation Copyright © 1997 by МАИК Наука/Interperiodica Publishing (Russia).

Comments to the Article of S.S. Lazarev "Peculiar Features of Typification in Stratigraphic Classification"[1]

A. I. Zhamoida

All-Russia Institute of Geology, Srednii pr. 74, St. Petersburg, 199026 Russia

Received July 26, 1995

Key words: *stratigraphic classification, typification, global scale, reference section, stratigraphic unit.*

I think that the author's suggestions to change the procedure of typification in stratigraphy and make it similar to that in biology (to separate the name of the stratgraphic unit from the content, to consider units of lower rank as a stratotype, and divide the "stratotype" notion into archetype, diagnosis, and nomenclature type) will never be accepted by stratigraphers. In my opinion, this is good because such proposals can only lead to confusion, which will result, above all, in the collapse of geological mapping.

However, the case in point includes another problem. Species is considered as a type for the genus because, among other things, it exists in the same time interval as the latter. At the same time, the single bed (or member) cannot represent a type for the formation because it reflects (among other things) the stratigraphic range (the time interval of the accumulation), which is quite different from that of the formation, not to mention the different contents of the formation and the single bed. Hence, nothing can be done in geology by ignoring the entitative aspect.

I think the author is wrong in thinking that a global scale is accidental in its entitative and hierarchical aspects. Surprisingly, the contingency appeared to be consistent on the planetary (!) scale. Numerous studies dealing with so-called event stratigraphy showed that this standard is not conditional. When revising the boundaries of major Phanerozoic stratigraphic units, Walliser, the acknowledged leader of event stratigraphy, arrived at the important conclusion that most of these boundaries in fact reflect certain events, i.e., global changes playing a considerable role in the evolution of organisms and ecosystems (Walliser, 1989; Zhamoida *et al.*, 1991). Consequently, the global Phanerozoic stratigraphic scale, though being elaborated mainly on European materials, is, in fact, the global one (at least at the subseries and, often, stage levels).

A global scale is a standard, but not an arbitrary and abstract one. Sokolov, admitting the somewhat abstract character of stratigraphic units (but not considering them as an absolute abstraction) wrote: "the specificity of a global scale consists only in the fact that it reflects the continuity of stratigraphic succession (as a consequence of purely regional synthesis); that is why it is acknowledged to represent the international chronostratigraphic standard" (Sokolov, 1971, p. 160). It is not accidental that Teslenko (1976) used the term *integration* when explaining the relationships of local and regional units with those of the global scale. The former units relate to the latter ones as a quotient to universal. This idea was used as a basis for the elaboration of Russian stratigraphic codes (*Stratigraficheskii* ..., 1977, 1992).

The stratigraphic boundary is inferred not only by a diagnosis. Its stratotype is defined as a particular sequence in which the boundary position (point) is selected and legalized. A similar conception of the stratigraphic boundary was adopted when elaborating Russian stratigragraphic codes (*Stratigraficheskii* ..., 1977, 1992) and, recently, in the International Stratigraphic Guide (1994).

The reference section is, indeed, an original, but the author did not understand its role. It is necessary, first of all, for the elaboration of more or less reliable legends to geological maps.

The reasoning behind the author's passages about totalitarianism is just a tribute to fashion. The uniform understanding of objects and events is one of the conditions of fruitful scientific research performed by many teams. This is quite natural. Codes do not "impose" decisions concerning entitative aspects but summarize the majority of current opinions. Nobody is ordered to think and understand in any other way.

Most surprising for me was the author's statement that "hierarchy of stratigraphic units and the position of boundaries in the global scale *must* change," though, true, only "jumpwise," after giving up old conceptions. And here, the author notes that "the maturity of new conceptions" is, to large extent, "a subjective matter." However, life advises us to change something only in

[1] See this issue, pp. 185–197.

those cases when they must be changed. This is true for stratigraphy as well.

Despite my disagreement with almost all the conceptions and suggestions of the author, I recommended his article for publication. In this article, the author's ideas are presented clearly (unlike in the publications of many other authors), and, consequently, everybody who wishes can dispute with him.

Reviewer A.Yu. Rozanov

REFERENCES

International Stratigraphic Guide. Second Edition, Salvador, A., Ed., Geol. Soc. Amer. Inc., 1994.

Sokolov, B.S., Biochronology and Stratigraphic Boundaries, in *Problemy obshchei i regional'noi geologii* (Problems of General and Regional Geology), Novosibirsk: Nauka, 1971, pp. 155–178.

Stratigraficheskii kodeks SSSR (Stratigraphic Code of the USSR), Leningrad: Vses. Inst. Geol (VSEGEI), 1977.

Stratigraficheskii kodeks. Izdanie vtoroe, dopolnennoe (Stratigraphic Code. Second Edition, Supplemented), St. Petersburg: Mezhved. Stratigr. Komitet, 1992.

Walliser, O., Use of Global Changes for Stratigraphical Subdivision, *Abstracts of Papers, 8th Int. Geol. Congr.*, Washington, 1989, vol. 3, p. 317.

Zhamoida, A.I., Rozanov, A.Yu., Semikhatov, M.A., *et al.*, Problems of Stratigraphy and Paleontology, in *Problemy geologii i poleznykh iskopaemykh na XXVIII sessii Mezdunarodnogo geologicheskogo kongressa* (Problems of Geology and Mineral Resources at the 28th Int. Geological Congr.), Moscow: Nauka, 1991, pp. 11–27.

Stratigraphy and Geological Correlation, Vol. 5, No. 2, 1997, pp. 200–204. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 5, No. 2, 1997, pp. 107–112.
Original Russian Text Copyright © 1997 by Simakov.
English Translation Copyright © 1997 by MAIK Nauka/Interperiodica Publishing (Russia).

Stratigraphic and Taxonomic Units (Comments to the Paper of S.S. Lazarev "Peculiar Features of Typification in Stratigraphic Classification")[1]

K. V. Simakov

Northeastern Complex Research Institute, Far East Division, Russian Academy of Sciences, Parkovaya ul. 16, Magadan, 685000 Russia

Received August 25, 1995

Key words: *stratigraphic classification, typification, global scale, reference section, stratigraphic unit.*

The appearance of the paper of Lazarev, in which he considers not only typification problems outlined in the title, but also most of the problems of recent stratigraphic theory and even some aspects of the theory of science as a whole, is not an accidental event. The author is undoubtedly a researcher not indifferent to the crisis in modern stratigraphy, which motivated him to discuss the, at first glance, particular question concerning typification of stratigraphic units along with an extremely wide range of problems. For a long time many researchers (Meyen, 1985, 1989; Krut', 1973, 1978; Krasilov, 1970, 1977; Krasilov *et al.*, 1985; Zubakov, 1978, 1992; and others) who used more or less different methodological approaches have been looking for a way to overcome the crisis developing in theoretical stratigraphy. Works on the perfection of the stratigraphic code that were conducted by a group of our authoritative stratigraphers under the general leadership of Zhamoida for more than 25 years are also a reflection of this crisis. Therefore, I would advise the author, first of all, to think twice before throwing stones into the crystal palace of stratigraphic codes and reproaching their elaborators for the contradictory character of some wordings. The codes reflect, on the one hand, compromises (necessary at the recent stage of the development of stratigraphy) between alternative viewpoints of researchers persistently advocating their own conceptions and, on the other, insufficient elaboration of the methodological basis of a general stratigraphic theory, as was justly noted by Meyen (1989).

Contrary to other researchers, who more (Krut') or less (Zubakov) explicitly tied their hopes for the perfection of the theoretical basis of stratigraphy, to the system approach, Lazarev sees a way to overcome the current crisis in stratigraphy by adopting principles and methods of zoological systematization by direct analogy. It is difficult to accept this point of view for several reasons.

First, while justly criticizing the modern chronostratigraphic concept, the author ignored the fact that its final form, vulnerable to philosophical (methodological) criticism, resulted from the development of views that were shared by creators of the International Stratigraphic Scale (ISS) whose position did not differ from that of Lazarev.

Indeed, Renevier (1874, 1897), when proposing his system of hierarchically coordinated universal units, used an analogy with zoological systematization. While introducing this hierarchical system into stratigraphy, he at the same time also accepted the conventional nature of any taxonomic categories, a concept typical of evolutionists of the second half of the 19th century (and inherited by recent taxonomists). However, in so doing, he has "forgotten" to introduce into stratigraphy the key idea of any classification—the general basis for comparison (subdivision) of the objects to be classified. Owing to this, the so-called stratigraphic classification is not now and never was a classification in the generally accepted meaning, i.e., sorting a great number of objects to classes (categories, taxons) according to the degree of their similarity and dissimilarity.

However, the use of the analogy with zoological taxonomy when constructing the ISS was completely erroneous (though quite understandable from the psychological point of view). Moreover, this approach contradicted the initial intention of Renevier himself because he considered the ISS to be a *chronometer* or *chrongraph*, i.e., a tool for defining the time (age) properties and relationships between local (regional) stratigraphic units.

From this point of view, the introduction of a hierarchically coordinated system of universal chronological units (Renevier considered precisely these units to be primary in his classification) made it necessary to use the analogy with the hierarchy of natural original units of ordinary time (year, month, day). However, this required entitative definitions of Renevier's units (era,

[1] See this issue, pp. 185–187.

period, epoch, age) to be introduced. Such definitions, if they are given, would then require the essential reorganization of the spontaneously developing system of successive stratigraphic units, which served, according to the decision of the 2nd International Geological Congress (IGC), as standards for the ISS units and the revision of their volume and boundaries. Nevertheless, neither Renevier nor the participants of the 3rd and 4th sessions of the IGC followed this path. Instead, they first introduced into stratigraphy (again by analogy with zoological systematization) the priority principle, owing to which they acquired the privilege to designate with the same terms (stage, period, etc.) units that were initially established based on their fully different properties. Second, they returned to Renevier's initial proposal favoring the chronological (not stratigraphic) units and defining them as units corresponding to "cycles in evolution of mainly pelagic faunas" (again, without indicating what the term *cycle* means). In other words, after the 8th IGC, geochronological units were considered to represent those of paleobiologic time. By the way, this view was shared by Schenck and Muller who proposed the term *time-stratigraphic unit* to designate them (Schenck and Muller, 1941, p. 1420). The concept of absolute time separated from the material substrate was pressed on the International Subcommission on Stratigraphic Classification by H. Hedberg despite the desperate opposition of Schindewolf, Yeletzky, Teichert, and other stratigraphers. However, it should be remembered that the chronostratigraphic concept "inherited" views on the artificial character of ISS units and the conventional nature of their boundaries precisely from the initial concept resting on an analogy between stratigraphic and biologic classifications and completely sharing the postulates of evolutionary theory (Nikitin and Chernyshev, 1889).

Thus, precisely the analogy with zoological taxonomy used in stratigraphy led to the situation in which we now find ourselves, i.e., to this chaos, which was created by ourselves and which, in Lazarev's opinion, can somehow be regulated by applying the same approach that caused this chaos. Therefore, sharing Lazarev's basic view on the necessity to accord the ISS structure with different, hierarchically coordinated stages of the evolution of a certain process, I cannot share his optimism that this can be reached by introducing biologic classification principles into stratigraphy. Until such time when entitative definitions of main notions (stratigraphic unit, zone, stage, etc.) are formulated in stratigraphy and the common basis for their comparison is defined, one cannot speak about true scientific stratigraphic classification. By the way, this is also recognized by the creators of stratigraphic codes who try to introduce strict regulation in the use of some terms. And this is not a reflection of totalitarianism aimed at the restriction of creative activity, as Lazarev believes, but simply an attempt to put in order current notions and to create the prerequisites for starting work on stratigraphic classification. Of course, it is quite a different matter that elaboration of entitative definitions is not a prerogative of codes and that proposed definitions are not always adequate, etc. Here, one should agree with Lazarev (and not only with him).

Simultaneously, I cannot agree with Lazarev's statement on the inadmissibility in principle of the introduction into stratigraphy of entitative definitions which would not only restrict the use of such terms as *stage, zone,* and others, but also regulate the procedure of their establishment, i.e., transform these terms from labels arbitrarily attached to units into scientific *notions*. The possibility for and necessity of regulation (or more precisely, elaboration) of the conceptual–terminological basis of stratigraphy is determined, in my opinion, first, by the nature of the system[2] of the object of stratigraphy (the stratisphere) and, second, by the general goal of any scientific study to define the regularities in structure and evolution of the object in question. The acknowledgment of the unlimited "freedom of creative activity" in defining stratigraphic units inevitably results in a subjective and distorted reflection of reality (in accordance with the author's conception) whereas the legalization of the content and volume of these arbitrarily defined units using the procedure of typification and standardization proposed by Lazarev will again result in chaos. The fact that biology is not able so far to introduce entitative definitions for the taxonomic categories it uses means that it has not yet reached the stage of discovering general regularities in the structure and evolution of living substance as an indivisible system. Nevertheless, this cannot serve as a pretext to raise the incompleteness of our recent knowledge to a universal principle and spread it over other sciences.

By the way, defending the "freedom of creative activity" while defining stratigraphic units, Lazarev involuntarily contradicts his own basic statement that the global (international) scale should be considered as a reflection of time succession of hierarchically coordinated geological events related to historical–geological processes of different scales. Postulating the necessity of reorganizing the modern ISS structure to accord it with the entitative hierarchy of geohistorical evolution,[3] the author thus voluntarily or, most likely, involuntarily also admits the existence of objective prerequisites for introducing entitative definitions of different units at least on a global scale. Such definitions (which, by the way, were proposed in instructive documents of the Interdepartmental Stratigraphic Commission of the USSR issued in 1954–1965), on the one hand, strictly regulate both the use of some terms and the definition procedure for stratigraphic units and, on the other, disavow the very idea of appliying principles of biologic systematization in stratigraphy. The proce-

[2] This nature, by the way, objectively restricts the "freedom" of defining stratigraphic units with 15 types of system transformations (Urmantsev, 1974).

[3] I do not consider here the validity of this point of view for the nature of ISS units, which does not reflect the initial idea of its creators and is opposed by many recent researchers.

dure used in biology suits only a science that is not ready, for some both objective and subjective reasons, to accept entitative definitions of terms used for designating hierarchically coordinated taxonomic categories.

I would like to emphasize that the aforesaid concerns the ISS units but also *mutatis mutandis* relates to both correlative and registration (according to author's terminology) units. Meanwhile, Lazarev proposes to use the principles of biological classification, typification, and standardization in stratigraphy in general, i.e., not only for global, but also for regional and local scales. Again, this can hardly be accepted because of the following considerations.

First of all, regional and local stratigraphy deals with the *subdivision* and *correlation*, but not with the *classification* of stratigraphic units because it does not use any feature in common for comparison of defined units (formations and others) and does not group them into certain classes according to the degree of their similarity and dissimilarity. As was emphasized by Meyen (1989), a taxon is not an analogue of a stratigraphic unit. A taxon always comprises a group of objects united by similarity–dissimilarity relationships that are interpreted to indicate the genetic unity (relationship) of these objects. The local *stratigraphic unit* (formation and others) represents a unique, single object (more precisely, the thing, see Krut', 1978) defined as a result of its separation from the whole, namely from the section of a certain region, but not as a result of uniting (grouping) of several objects similar to each other with some features in common. Therefore, it is not accidental that Meyen (1989, p. 77) proposed that the main stratigraphic procedure be termed *stratonomy*, meaning the totality of subdivision principles, and opposed this to *taxonomy* that unites the principles of defining taxa. Being perfectly aware that the stratonomic procedure leads to the separation of individuals, whereas the taxonomic one is concerned with their uniting (grouping), Meyen had no time for the conclusive development of this idea and the formulation of stratigraphic subdivision principles.

Further, the essential difference between taxonomic and stratigraphic units consists also in the fact that the latter units generally represent records of mobile–equilibrated geo- and paleoecosystems of different scales and are *systems* themselves. The possibility of subdividing stratigraphic units is conditioned by their element–component spatial–temporal structure. Such a structure suggests the opportunity to subdivide the regional stratigraphic unit in both intensive (according to evolutionary stages) and extensive (in accordance with spatial heterogeneity) aspects. Stratigraphic units of lower rank obtained by one or another (or combined) method of subdivision also represent individual systems (subsystems) that are entitatively unequal both to each other and to the stratigraphic unit (system) uniting them. Precisely this precludes the application in stratigraphy of one of the main principles of biologic classification—the principle of hierarchy—which, according to Lazarev, must be used.

By the way, if the method of analogies proposed by Lazarev is to be used, then the analogy with chemical compounds or minerals would better demonstrate the impossibility of applying the principle of hierarchy for the typification of regional and local stratigraphic units. Indeed, stratigraphic units as geosystems result from the interaction ("reaction") of inert, bioinert, and biologic systems of the past, whose products represent primary (elemental) components ("atoms") of the units. Following this analogy, one can construct a two-level hierarchical system of stratigraphic units whose lowest level will be represented by genetically homogenous (inert, bioinert, biogenic) beds (=atoms of chemical elements), whereas the highest level will be the combination of beds (=chemical compounds, minerals). In this case, the classification of stratigraphic units can be based on principles of chemical or mineralogical systematization, i.e., on defining taxons, or groups of stratigraphic units by similarity of composition and thus analogous to alkalies, bases, acids, etc. in chemistry, and to oxides, silicates, aluminosilicates, etc. in mineralogy. Such a classification of stratigraphic units, which is phenomenological in its essence, has full right to exist and could form a special topic in stratigraphy ("stratilogy," by analogy with mineralogy). However, the point is that the considered "chemical–mineralogical" (contrary to "biologic") analogy allows us to understand better the fundamental difference between stratonomic and taxonomic procedures. During stratigraphic subdivision, we "decompose" the geosystem (compound, mineral) into subsystems (atoms) composing and hierarchically subordinate to this system. In their properties, these subsystems are analogous neither to each other nor to the parental system. In this respect, stratonomy is analogous to chemical reaction of decomposition. Decomposing water to oxygen and hydrogen, we obtain substances that differ in their properties, represent gas rather than liquid, and are related to the other (atomic) level of organization. If the logic of biologic classification is accepted, then what should be considered, according to the principle of hierarchy, to represent the water—oxygen or hydrogen? In other words, the stratonomic procedure results in defining objects of different organization levels, within which systematization of related subsystems (things) is possible based on certain properties characteristic only of this peculiar level. For instance, the inert components of stratigraphic units can be divided by their genesis into volcanogenic, clastogenic, and chemogenic (with their possible further subdivision into types). However, none of these components can represent the nomenclature type of a complicated volcanogenic-sedimentary formation, unlike the biologic classification where species represents the genus nomenclature type.

Finally, the construction of regional stratigraphic scales representing models of primary space–time relationships of local stratigraphic units based on their grouping into correlative subdivisions is also not analogous to the procedure of biologic taxa definition; this rather can be compared with the procedure of homologization in biology, although the latter is entitatively different. Homologization in biology is, if one can say so, of the volumetric type, i.e., it deals with objects variable in age (limbs of Paleozoic reptilians and recent mammals are of homologous structure). Meanwhile, stratigraphic correlation has, figuratively speaking, a planar character and concerns only those objects that occupy a similar age position in spatially separated areas. If the correlation procedure is defined from the system standpoint, then it can be compared with the unravelling of the extensive (component) structure of a certain element in the intensive (time) structure of the regional stratigraphic complex. Coming back to the "chemical–mineralogical" analogy, one can say that correlative units represent more complicated compounds (as compared with local ones). If we draw the analogy between local units and oxides or silicates, then correlative units can be compared with aluminosilicates.

Naturally, the aforesaid does not exclude the principal possibility of stratigraphic classification at the regional or local levels in its real meaning, i.e., a distribution of local and regional age-variable stratigraphic units between classes (orders, taxons) according to the degree of their similarity–dissimilarity. However, this procedure is possible only by using entitative definitions (such as definitions of oxides, silicates, etc. in mineralogy) of those terms that are used in the designations of regional and local stratigraphic units (horizons, formations, etc.). The elaboration of the principles of such classification will make it possible both to put in order stratigraphic terminology and to standardize the stratonomic procedure, but not, of course, to replace it. Naturally, this work will require that we take into account all the positive experience accumulated in biological, chemical, and mineralogical systematizations.

Evidently, the specific nature of stratigraphic units and their principal difference from biologic taxons determine the peculiar procedure of their typification and standardization. This is not taken into full consideration by the author of the article. In addition to the impossibility of using the hierarchy principle, the typification of regional and local stratigraphic units at both phenomenological ("chemical–mineralogical") and system levels requires their entitative definitions, i.e., the elaboration of a system of taxonomic categories. Therefore, in the absence of entitative definitions regulating a procedure for the establishment of stratigraphic units, I do not consider the materialization of stratostandards (the organization of something like a stratigraphic chamber of measures and weights) to be very fruitful. I also think that this idea is poorly thought over, because the very notion of the "standard" itself means some thing quite different in geology than in metrology. Standardization in stratigraphy means the legalization of the phenomenological features of a particular stratigraphic unit that allow its spatial distribution to be traced. In doing so, we are forced to standardize, on the one hand, characteristic features of the stratigraphic unit itself, which represents the record of a certain state of geo- or paleoecosystems of this or that scale, and, on the other, its boundaries, which are records of events that resulted in a new state of these systems. Besides, when considering different units (universal, correlative, and registration ones, by the author's terminology), problems of typification (classification) and standardization should be solved in different ways. For instance, concerning the local (registration) units, the stratotype, as a carrier of the nomenclature type, and stratostandard can probably coexist in a single section (Zhamoida, 1980, p. 36) to provide the stability of local stratigraphic scales and legends for geologic maps. Nevertheless, taking into account the nature of stratigraphic units, the necessity of several reference sections, which represent standards for subsystems composing the stratigraphic unit, i.e., the geosystem, also seems quite logical. In addition, when determining whether reference sections are unique or multiple, formal requirements to stratigraphic units (thickness etc.) should also be taken into account from the viewpoint of performing geological mapping of a different scale. Generally, the larger the mapping scale is, the smaller will be the stratigraphic units as shown in their spatial–temporal range on the map. As for correlative units, the conception of their diagnostics, which was intelligibly presented by the author, can probably be applied to them.[4] If I correctly understood, the author suggests to standardize their boundaries and give a diagnosis of chronologically interchangeable features, according to which they can be traced. In this case, it would be possible to define only the boundary stratotypes of correlative units. Finally, the establishment of stratostandards for universal stratigraphic units seems unnecessary, because it would be sufficient just to provide their diagnoses (for instance, the Sturian can be considered as deposits with mixed Devonian–Carboniferous fauna). However, as with correlative units, their boundary stratotypes, which record events that represent natural boundaries between universal units, need to be

[4] In this context, the term *stratoarchetype* proposed by the author is extremely flimsy because this term is considered to mean invariant features of a taxon, which distinguish it from close taxons (Meyen, 1989). However, both correlative and universal stratigraphic units are not analogous to taxons, and particular sections representing them can by no means be likened to separate individuals united into the taxon, because they represent a part of the whole (merons) rather than individuals. The idea of a stratoarchetype could be pertinent if entitative definitions of stratigraphic units existed. In this case, one could speak, as in chemical–mineralogical classification, about archetypes of various stratigraphic units similar, let us say, to oxides (R_2O, RO, R_2O_3, etc.). However, the author uses the term *stratoarchetype* to characterize separate stratigraphic units analogous to particular compounds (Na_2O, FeO, etc.).

defined.[5] As is evident from the foregoing, the hierarchical organization of the stratisphere as a whole and stratigraphic units of any (global, regional, local) level cannot adequately be deciphered using the direct analogy with biological classification. In the case where the hierarchy of ISS units (considered as an external system of coordinates for the global correlation of regional and local units, but not as a reflection of the global geohistorical process) is involved, an analogy with the hierarchy of natural primary units of ordinary time seems more appropriate. In another case, when we consider the hierarchy of regional (correlative) and local (or registration) units, an analogy with chemical–mineralogical classification is more suitable. To avoid confusion, I would like to stress that none of these analogies reveal a specific (space–time) essence of hierarchical coordination of stratigraphic units, which apparently should be used as a basis for their classification. It is also important to emphasize here that both of them reinforce the point that natural classification is impossible without entitative definitions of terms to be used when describing natural events, i.e., without an elaboration of the conceptual–terminological basis that regulates both the use of terms and a procedure for defining pertinent phenomena. All the comments also concern the author's principal views, which, as he perfectly recognizes himself, essentially differ from the viewpoint, according to which stratigraphic classification, as such, does not and never can exist. I agree completely that stratigraphic classification does not exist at the moment, but I cannot accept the viewpoint that it is impossible in principle, and in this respect the statement of the problem by Lazarev deserves approval and support of any kind. Another matter is that I cannot accept his suggested method to attack this fundamental stratigraphic problem. In principle, I agree with Meyen's viewpoint who wrote, noting the close relationship and interdependence of biology and stratigraphy: "It is even more surprising that the union with biology did not hinder the development of stratigraphy. The evolution of prevailing biological doctrines only indirectly affected stratigraphic scales. On the other hand, it directly intervened into attempts to formulate principles of stratigraphy and to explain the nature of stratigraphic units and boundaries. Though the union with biology was fruitful, precisely this union is responsible for the confusion in many stratigraphic conceptions" (Meyen, 1989, pp. 88–89). From this standpoint the discussed work of Lazarev could have been considered another "act of aggression" of biology against stratigraphy had it not been motivated by the best intentions of its author. Nevertheless, I should stress that my viewpoint presented here is also far from being indisputable. Being aware of that, contrary to the author of the considered paper, I am not going to burden other researchers and, even more, developers of stratigraphic codes with any recommendation concerning various procedural problems.

Reviewer A.Yu. Rozanov

[5] Unfortunately, the author has not adequately analyzed the problem of stratigraphic boundaries, which relates to a more general methodological problem concerning the role of trivial and nontrivial conventions (agreements) in the theorethical–cognitive apparatus of stratigraphy (Simakov, 1986, and others).

REFERENCES

Krasilov, V.A., Paleoecosystems, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1970, no. 4, pp. 114–120.

Krasilov, V.A., *Evolyutsiya i biostratigrafiya* (Evolution and Biostratigraphy), Moscow: Nauka, 1977.

Krasilov, V.A., Zubakov, V.A., Shul'diner, V.I., and Remizovskii, V.I., *Ekostratifrafiya. Teoriya i metody* (Ecostratigraphy. Theory and Methods), Vladivostok, 1985.

Krut', I.V., *Issledivanie osnovanii teoreticheskoi geologii* (Analysis of Fundamentals of Theoretical Geology), Moscow: Nauka, 1973.

Krut', I.V., *Vvedenie v obshchuyu teoriyu Zemli* (Introduction to the General Theory of the Earth), Moscow: Mysl', 1978.

Meyen, S.V., Structure of Theoretical Stratigraphy, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1985, no. 11, pp. 8–16.

Meyen, S.V., *Vvedenie v teoriyu stratigrafii* (Introduction to Theory of Stratigraphy), Moscow: Nauka, 1989.

Nikitin, S.N. and Chernyshev, F.N., Int. Geological Congr. and Its Last Sessions in Berlin, *Gorn. Zh.*, 1889, vol. 1, no. 1, pp. 114–150.

Renevier, E., *Tableau des terrains sédimentaires formés pendant les époques de la phase organiqué du globe terrestre avec leurs représentánts en Suisse et dans régions classiques, leurs synonymes. et les principaux fossiles de chaque etage*, Lausanne, 1874.

Renevier, E., Resume du chronographe geologique, *Bull. Soc. Vaudoise Sci. Nat.*, 1897, vol. 33, pp. 1–7.

Schenck, H.G. and Muller, S.W., Stratigraphic Terminology, *Geol. Soc. Am. Bull.*, 1941, vol. 52, pp. 1419–1426.

Simakov, K.V., *Problema opredeleniya khronostratigraficheskikh granits (na primere granitsy devona i karbona)* (The Problem of Definition of Stratigraphic Boundaries (the Devonian–Carboniferous Boundary as an Example)), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., Dal'nevost. Otd. Akad. Nauk SSSR, 1986.

Urmantsev, Yu.A., *Simmetriya Prirody i priroda Simmetrii* (A Symmetry of Nature and the Nature of Symmetry), Moscow: Nauka, 1974.

Zhamoida, A.I., The Essence and Relationship of Main Stratigraphic Units, in *Stratigraficheskaya klassifikatsiya: Materialy k probleme* (Stratigraphic Classification: Materials Regarding the Problem), Leningrad: Nauka, 1980, pp. 32–63.

Zubakov, V.A., *Ritmostratigraficheskie podrazdeleniya. Proekt dopolnenii k stratigraficheskomu kodeksu SSSR* (Rhythmostratigraphic Units. Draft of Supplements to the Stratigraphic Code of the USSR), Leningrad: Vses. Geol. Inst., 1978.

Zubakov, V.A., A New Approach to Stratigraphic Classification, *Sov. Geol.*, 1992, no. 5, pp. 46–53.

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by МАИК Наука/Interperiodica Publishing

Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	RATE IN US DOLLARS INTERNATIONAL	YOUR ORDER
❑	Agricultural Chemistry	1	Pending	4	$459	$529	$ _____
❑	Computational Mathematics and Mathematical Physics	37	0965-5425	12	$1813	$2208	$ _____
❑	Doklady Mathematics	55/56	1064-5624	6	$1099	$1264	$ _____
❑	Entomological Review	77	0013-8738	9	$1689	$1942	$ _____
❑	Eurasian Soil Science	30	1064-2293	12	$1597	$1837	$ _____
❑	Geochemistry International	35	0016-7029	12	$1800	$2070	$ _____
❑	Geology of Ore Deposits	39	1075-7015	6	$769	$884	$ _____
❑	Geotectonics	31	0016-8521	6	$435	$472	$ _____
❑	Herald of the Russian Academy of Sciences	67	1019-3316	6	$949	$1205	$ _____
❑	Izvestiya, Atmospheric and Oceanic Physics	33	0001-4338	6	$605	$650	$ _____
❑	Izvestiya, Physics of the Solid Earth	33	1069-3513	12	$638	$702	$ _____
❑	Journal of Communications Technology and Electronics	42	1064-2269	12	$2091	$2405	$ _____
❑	Journal of Computer and Systems Sciences International	36	1064-2307	6	$1670	$1921	$ _____
❑	Journal of Ichthyology	37	0032-9452	9	$1451	$1669	$ _____
❑	Laser Physics	7	1054-660X	6	$874	$1055	$ _____
❑	Oceanology	37	0001-4370	6	$539	$581	$ _____
❑	Paleontological Journal	31	0031-0301	6	$1084	$1247	$ _____
❑	Pattern Recognition & Image Analysis	7	1054-6618	4	$549	$631	$ _____
❑	Petrology	5	0869-5911	6	$769	$884	$ _____
❑	Polymer Science. Series A	39	0965-545X	12	$2078	$2390	$ _____
❑	Polymer Science. Series B	39	Pending	6	$787	$905	$ _____
	Both Series A & B. $200 discount				$2665	$3095	$ _____
❑	Proceedings of the Steklov Institute of Mathematics	216-219	0081-5438	4	$809	$930	$ _____
❑	Russian Journal of Inorganic Chemistry	42	0036-0236	12	$2151	$2474	$ _____
❑	Russian Journal of Physical Chemistry	71	0036-0244	12	$2151	$2474	$ _____
❑	Russian Journal of Zoology	1	Pending	4	$459	$529	$ _____
❑	Stratigraphy and Geological Correlation	5	0869-5938	6	$769	$884	$ _____
❑	Studies on Russian Economic Development	8	1075-7007	6	$549	$631	$ _____
❑	The Physics of Metals and Metallography	83/84	0031-918X	12	$1876	$2157	$ _____
❑	Thermophysics and Aeromechanics	4	0868-8643	4	$499	$599	$ _____
❑	Thermal Engineering	44	0040-6015	12	$1198	$1378	$ _____
❑	Transactions of the Russian Academy of Sciences/Earth Science Sections	352-357A	0012-494X	9	$2287	$2630	$ _____

TOTAL _____

❶ Name _____
Institution _____
Address _____
_____
City _____ State _____
Zip/Postal Code _____ Country _____
Telephone (_____) _____

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**
or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $_____ is enclosed.
OR
❑ Bill me. My library's purchase order number is _____

❸ Send this order and payment to:
INTERPERIODICA
P.O. Box 1831
Birmingham, AL 35201-1831
Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 1997!

МАИК НАУКА/INTERPERIODICA PUBLISHING

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

МАИК НАУКА (NAUKA International Academic Publishing Company), in cooperation with the Russian Academy of Sciences, publishes the results of research in all fields of modern science performed by leading scientists and scientific institutions from Russia, the CIS, and other countries. Simultaneous English translation of the journals is provided by INTERPERIODICA Publishing, the translation division of МАИК НАУКА. Today, scientists around the world have direct access to the most significant Russian research at the time it is first published in Moscow – at the time it is most relevant to the worldwide scientific community. In addition to more timely publication, readers benefit from more precise translations of each journal, provided by a carefully chosen team of scientific translators with direct access to the authors and editors. English versions of the journals published by МАИК НАУКА/INTERPERIODICA PUBLISHING are distributed worldwide by INTERPERIODICA, Plenum/Consultants Bureau, and the American Institute of Physics.

МАИК НАУКА 1997 volumes include the following titles:

- *Agricultural Chemistry*
- *Computational Mathematics and Mathematical Physics*
- *Doklady Mathematics*
- *Entomological Review*
- *Eurasian Soil Science*
- *Geology of Ore Deposits*
- *Geochemistry International*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journals of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petrology*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Physical Chemistry*
- *Russian Journal of Zoology*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermophysics and Aeromechanics**
- *Thermal Engineering*
- *Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Sections*

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831. For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588.
* *Thermophysics and Aeromechanics*: Only distributed by МАИК НАУКА/Interperiodica

- *Applied Biochemistry and Microbiology*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Cosmic Research*
- *Doklady Biochemistry*
- *Doklady Biological Sciences*
- *Doklady Biophysics*
- *Doklady Botanical Sciences*
- *Doklady Chemical Technology*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Evolutionary Biochemistry and Physiology*
- *Journal of Analytical Chemistry*
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Microbiology*
- *Molecular Biology*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Solar System Research*
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

Please direct all inquiries about the above journals to: **Plenum/Consultants Bureau**, 233 Spring Street, New York, NY 10013. Phone: (212) 620-8467. Fax: (212) 807-1047.

- *Acoustical Physics*
- *Astronomy Reports*
- *Astronomy Letters*
- *Crystallography Reports*
- *Optics and Spectroscopy**
- *Physics—Doklady*
- *Physics of Atomic Nuclei*
- *Plasma Physics Reports*

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, 500 Sunnyside Boulevard, Woodbury, NY 11797-2999 USA. Tel. (516) 576-2270, (800) 344-6902. Fax: (516) 349-9704.
* *Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 223-1096.

МАИК Наука/Interperiodica Publishing (International Academic Publishing Co. "Nauka")
Profsoyuznaya ul., 90, Moscow, 117864, Russia, Phone: 7 (095) 3361600; Fax: 7 (095) 336 0666, E-mail:compmg@maik.rssi.ru